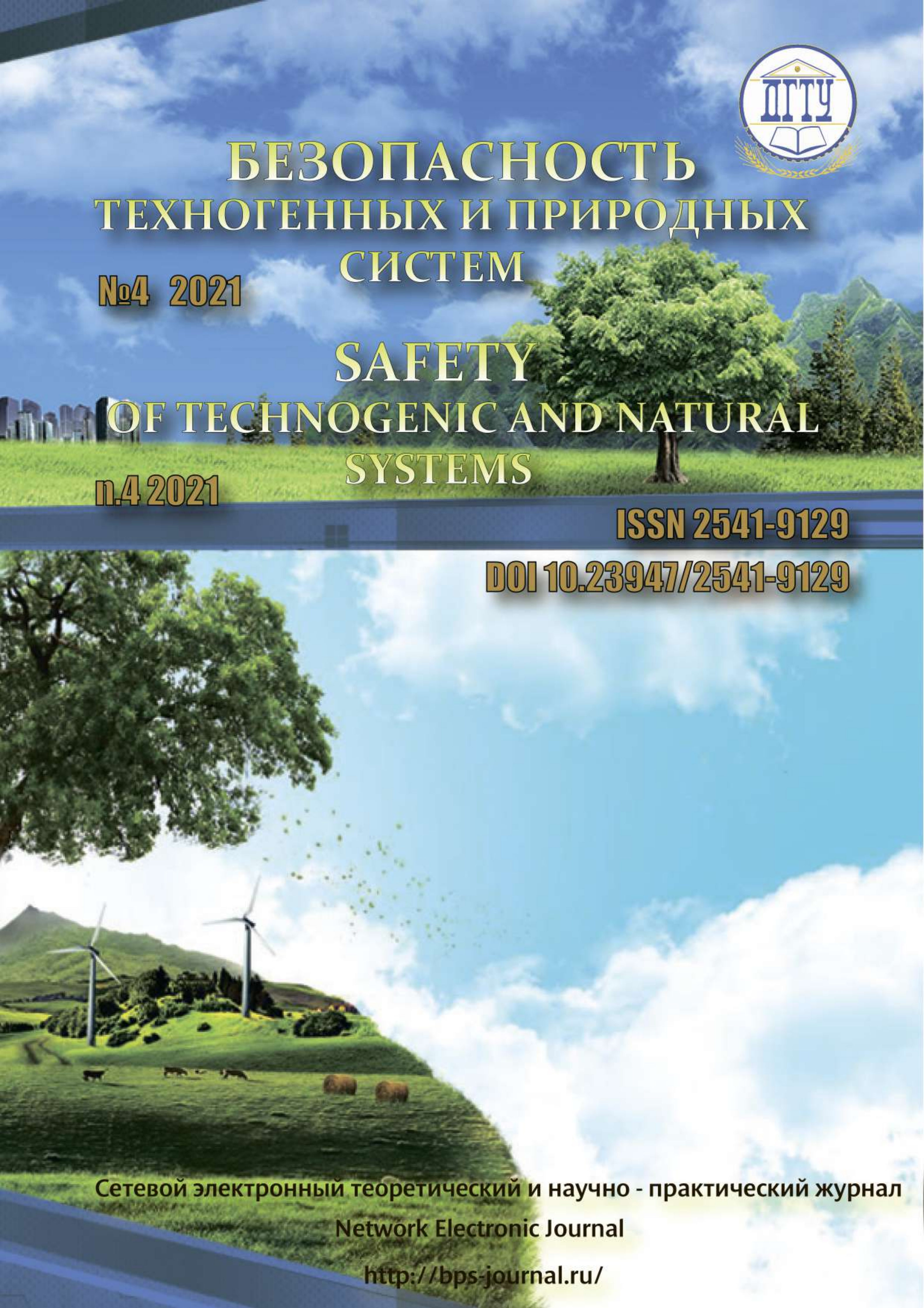

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Selection of a method for calculating heat gain from solar radiation to determine the load on the climate system of the cabin of a mobile car

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Introduction. The article analyzes and selects the most rational methods for calculating the heat gain from solar radiation. The correct calculation of this component of the heat balance allows you to correctly determine the power of the projected cabin climate system, which will ensure optimal working conditions at the workplace of mobile car operators.

Problem Statement. The objective of this study is to analyze and select a rational method for calculating heat gain from solar radiation for the correct determination of the thermal load on the climate system of the cabin of a mobile car.

Theoretical Part. To implement the task, the most common methods for calculating solar radiation were described and analyzed in detail and the most accurate ones were recommended.

Conclusions. The more labor-intensive method of V.N. Bogoslovskiy (taking into account the time of day) can be recommended for automated calculations in Excel, and the method of P.Y. Gamburg (taking into account the sides of the horizon) — for comparative estimated engineering calculations. When conducting "in-depth" model calculations and accounting for solar radiation, the ASHRAE method is explicitly suitable, which has two important advantages: it takes into account the solar factor in relation to a specific type of glazing and is adapted for automated calculations in ANSYS FLUENT.

Keywords: solar radiation, cabin, glazing, mobile car, climate control system.

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Introduction. Solar radiation accounts for a significant part of the heat inflow into the cabin of a mobile car (70-80 %) [1, 2]. This proves that the accuracy of determining the thermal load on the cabin climate system depends on the component of the Q_5 balance — solar radiation. Therefore, it is necessary to elaborate on its definition by analyzing various calculation methods and techniques. Moreover, the results of the calculations have very significant discrepancies among themselves. The amount of solar radiation obtained by the method [3, 4] is 30 % higher than that obtained by more modern methods, for example, by the ASHRAE method.

The light- and heat-transparent walls of the cabin are the most common ways of penetration of solar radiation, part of which (short-wave radiation) enters the cabin without obstacles, and the other part (convective heat) is absorbed by the glasses and enters due to the temperature difference. Figure 1 shows a diagram of the heat and humidity balance of the cab of a mobile car.

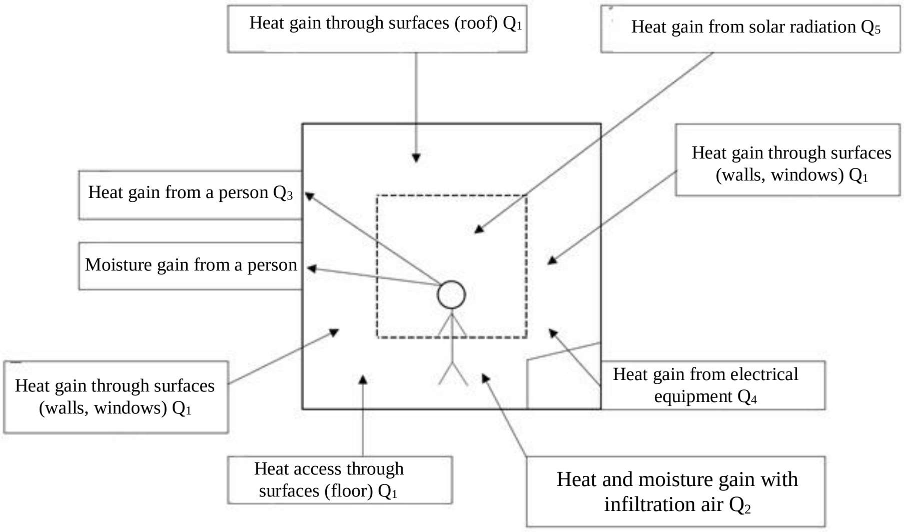
Heat gain through surfaces (roof) Q_1
Heat gain from solar radiation Q_5
Heat gain through surfaces (walls, windows) Q_1
Heat gain from a person Q_3
Moisture gain from a person
Heat gain through surfaces (walls, windows) Q_1
Heat gain from electrical equipment Q_4
Heat access through surfaces (floor) Q_1
Heat and moisture gain with infiltration air Q_2

Fig. 1. Calculation model of heat and moisture transfer to the cabin of a mobile car in summer

In addition to the heat gain from solar radiation Q_5, the most significant in the heat balance are heat flows through the surfaces Q_1; from the infiltrated air Q_2; from the operator Q_3; from lighting and electrical appliances Q_4 [5–8].

Problem Statement. The objective of this study is to analyze and select a rational method for calculating heat gain from solar radiation for the correct determination of the thermal load on the climate system of the cabin of a mobile car.

Theoretical Part. The main methods for calculating heat gain from solar radiation are the following.

Method 1

Only those surfaces that face the sun are taken into account. Heat inflows from solar radiation, taking into account the degree of transmission of sunlight:

$$Q_5 = (A_{\text{к}} \cdot I \cdot K_{\text{k}} \cdot F_{\text{k}})/\alpha_{\text{н}} + I \cdot K_{\text{б}} \cdot F_{\text{б}} + I \cdot K_{\text{ф}} \cdot F_{\text{ф}}, \tag{1}$$

where $A_{\text{к}}$ — the proportion of absorption of sunlight by the cabin roof; I — the intensity of radiation; $K_{\text{к}}$ — roof heat transfer coefficient, W/(m^2·K); $K_{\text{б}}$ and $K_{\text{ф}}$ — the coefficients of transmission of sunlight by glasses equal to $K_{\text{ф}} = 0.46$; $K_{\text{б}} = 0.8$; $F_{\text{к}}$, $F_{\text{б}}$ and $F_{\text{ф}}$ — the area of the roof and windows on the side and front wall, m^2.

This method gives an error in calculations due to the fact that the surfaces not facing the sun (side, back and floor) are under the influence of only scattered solar radiation, the magnitude of which is insignificant [2, 9, 10].

In the calculations, the outdoor air velocity was set to 0 m/s, and the indoor air was assumed to be 1.5 m/s. In this case, the total heat inflow from solar radiation was Q_5 = 2,603 W.

The total heat inflow through the cabin light openings was: $Q_{rad}^{glass} = 1155 + 1040 = 2195$ W.

Method 2

It is based on the calculation of the heat inflow from solar radiation through the cabin windows according to the method developed by P. Y. Hamburg (using shading coefficients) [6].

The total heat inflow into the cabin Q_{1c} (in watts) includes heat inflow through opaque walls and heat inflow through light openings, i.e.

$$Q_{1c} = Q_{1c}^{\text{mass}} + Q_{1c}^{\text{light}}. \tag{2}$$

Q_{1c}^{light} (W) is calculated for each side of the world:

$$Q_{1c}^{\text{light}} = Q_{\text{ок}} \cdot F \cdot \tau, \tag{3}$$

where $Q_{\text{ок}}$ — the specific heat inflow through a single glass, W/m^2; F — the window area, m^2; τ — the window shading coefficient by the shading device.

In our case, we select the coefficients τ from Table 1 according to the supplier's data from the technical characteristics of the glasses for the cabin of the mobile car.

Table 1

Technical characteristics of glasses

Glass	Thickness, mm	Light transmission, LT, %	Solar energy transmission, ET, %	Solar energy absorption, EA, %	Light reflection, LR, %	Reflection of IR radiation of the sun, % (estimated)
Colorless	4	90	83	9	8	7
	6	89	80	12	8	6
Planibel AGC green	4	80	56	38	7	6
	6	74	46	48	7	6
Planibel AGC blue	6	73	45	45	7	6
Planibel Torn	6	78	64	20	13	8
Pilkington, K-glass	4	82	61	9	11	19
	6	81	58	12	11	19
Pilkington, I-glass	4	86	61	5	9	26

The values of $Q_{ок}$ are given in the reference tables in [6]. At the same time, the greatest heat inflow is taken into account. Table 2 provides the results of the calculations of heat inflows from solar radiation through the cabin windows using the method of P. Y. Hamburg at 45° latitude of the cabin location at its different orientations on the sides of the horizon.

Table 2

Calculation of heat inflows from solar radiation through light openings, Krasnodar (45° latitude)

Cabins	Cardinal directions	Type of glazing	Area of the light opening, m^2	Heat gain according to the table	Shading coefficient, τ	$Q_{1c}^{свет}$, W
Orientation to the South						
1st cabin variant	South	Planibel AGC green	2.41	300	0.74	528.4
	North	Planibel AGC green	1.41	58	0.74	60.5
	East	Colorless	1.52	315	0.89	426.1
	West	Colorless	1.52	315	0.89	426.1
					Total	1 442
Orientation to the South-East						
1st cabin variant	South-West	Colorless	1.52	270	0.89	365.3
	North-East	Colorless	1.52	165	0.89	223.2
	South-East	Planibel AGC green	2.41	270	0.74	475.5
	North-West	Planibel AGC зеленое	1.41	165	0.74	172.2
					Total	1 236
South- East						
2nd cabin variant	South	Planibel AGC green	2.41	300	0.74	528.4
	North	Planibel AGC green	0.41	58	0.74	17.6
	East	Colorless	1.52	315	0.89	426.1
	West	Colorless	1.52	315	0.89	426.1
					Total	1 399

Method 3 (by shading)

Calculation of heat flows from solar radiation according to GOST 14 269-03 and CS 11765852-02-2016 [3]. Heat gain from solar radiation Q_{1c} consists of heat access through massive cabin surfaces and heat gain through light openings (formula (2)). Determination of heat gain from radiation light through the openings of the workplace according to the formula:

$$Q_{1c}^{свет} = I \cdot \sum_{i} (1 - K_i) \cdot F_i, \qquad (4)$$

where I — the intensity of solar radiation; K_i — the shading coefficient of the i-th surface; F_i — the area of the i-th light opening, m^2.

Taking into account the shading of the windows of the mobile car cabin, we will determine the heat flows from solar radiation through the light openings:

$$Q_{1c}^{light} = 950 \cdot (1 - 0{,}74) \cdot (2{,}41 + 3{,}8 + 1{,}4) = 2169 \text{ W}.$$

Then the heat gain from heat transfer through massive surfaces is equal to:

$$Q_{1c}^{ceiling} = K \cdot F \cdot \Delta t; \qquad (5)$$

$$Q_{1c}^{ceiling} = 1{,}87 \cdot 2{,}3 \cdot 21 = 91 \text{ Вт}.$$

The total heat flows through the glass amounted to 2,260 watts.

Method 4

Calculation according to the method of V. N. Bogoslovskiy [1, 10].

The total heat gain penetrating into the cabin through the light openings, W/m^2:

$$q_{\Sigma} = q_{\text{с.и.}} + q_{\text{т.п.}}. \tag{6}$$

The heat gain from solar radiation in case of a vertical cabin window is equal to, W/m^2:

$$q_{\text{с.и.}} = \left(q_{\text{пр}} \cdot K_{\text{инс}} + q_{\text{рас}} \cdot K_{\text{обл}}\right) K_{\text{отн}} \cdot \tau_2, \tag{7}$$

where $q_{\text{пр}}$, $q_{\text{рас}}$ — the heat gain taking into account direct and scattered solar radiation, W/m^2; $K_{\text{обл}}$, $K_{\text{отн}}$ — the coefficients of irradiation and relative penetration of solar radiation, respectively; τ_2 — the coefficient of shading of the light opening with bindings; $K_{\text{инс}}$ — the coefficient of insolation, determined according to the formula

$$K_{\text{инс}} = \left(1 - \frac{L_{\text{г}} \operatorname{ctg} \beta - a}{H}\right)\left(1 - \frac{L_{\text{в}} \operatorname{tg} A_{\text{с.о.}} - c}{B}\right), \tag{8}$$

where $L_{\text{г}}$, $L_{\text{в}}$ — the width of horizontal and vertical shading devices, m; β — the angle between the window surface and the perpendicular projection of the solar beam, in degrees; $A_{\text{с.о.}}$ — solar azimuth of the glazing; a, c — the distance between shading devices and the window, m; H, B — window height and width, respectively.

Figure 2 shows the results of the calculation of the total heat gain into the cabin through the light openings, and a graph of the heat gain from solar radiation by the hours of the day in the hottest summer month according to this method.

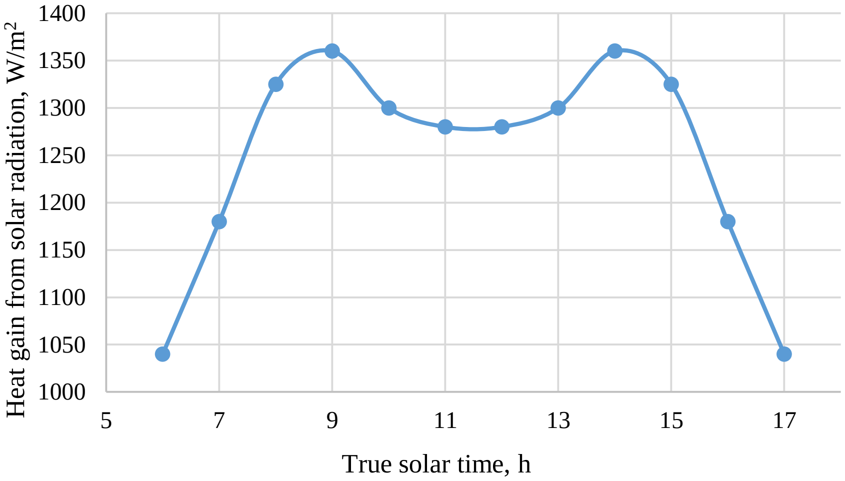

Fig. 2. Heat gain into the cabin from solar radiation by the hour of the day in July

Method 5

Calculation according to the methodology proposed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE [7].

The heat inflow from direct solar radiation $Q_{\text{п}}$ is equal to:

$$Q_{\text{п}} = S \cdot \text{SHGC}(\theta) \cdot \text{IAC}(\theta, \Omega) \cdot F_{\text{п}}, \tag{9}$$

where S — heat flow from direct solar radiation, W/m^2, falling on the wall, assumed to be equal depending on the geographical location, time of day and orientation of the cabin; SHGC(θ) — solar heat gain coefficient from direct solar radiation, depending on the technical characteristics of the double-glazed window and the angle of incidence θ; IAC(θ, Ω) —indoor solar attenuation coefficient from direct solar radiation, depending on θ, the presence of internal sun protection devices and the shadow angle Ω — the angle between the horizontal plane of the glazing and the projection of the sunbeam on the vertical plane perpendicular to the considered glazing plane; $F_{\text{П}}$ — glazing area, m^2.

The advantage of the described technique is that the heat inflow is determined relative to the flow on the wall, and the amount of radiant energy penetrating into the cabin is calculated due to the heat gain coefficient SHGC and the attenuation coefficient of the heat gain coefficient IAC. In this regard, it is necessary to define the term "solar factor". It means (g) the ratio of the total heat flow penetrating into the cabin to the flow of incident solar radiation (Fig. 3) [7].

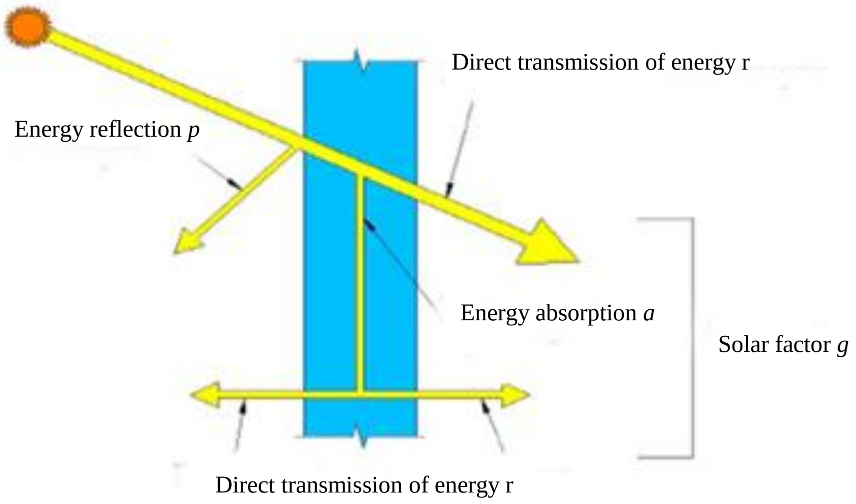
Direct transmission of energy r
Energy reflection p
Energy absorption a
Solar factor g
Direct transmission of energy r

Fig. 3. Physical meaning of the solar factor [7]

The solar factor is one of the main parameters given in the technical specifications for a double-glazed window [7]. In this case, the solar factor gives a real reference to a certain type of glass, taking into account direct and scattered solar radiation penetrating into the cabin, which eliminates the need to take into account additional values of $q_п$ and $q_р$. In this case, the formula for heat gain from scattered solar radiation is transformed:

$$Q_р = (S \cdot K_{инс} + 0{,}75D \cdot K_{обл}) \cdot g \cdot k_{СЗУ} \cdot \tau_2 \cdot F_п, \tag{10}$$

where g — solar factor of the glass; $k_{СЗУ}$ — the heat transmission coefficient of sun protection devices.

It should also be noted that the basic principles of the ASHRAE methodology have been introduced into the ANSYS software package, which makes it attractive for practical model calculations. In the solar load model, it is possible to obtain data on the amount of solar radiation in a specific period of time using the solar calculator program.

Let us summarize in Table 3 the total values of heat gain from solar radiation to the workplace of the mobile car operator, calculated by various methods.

Table 3

Total values of heat gain from solar radiation

Calculation method	Without taking into account the sides of the horizon	GOST 14269-03, not taking into account the sides of the horizon	Method of P. Y. Hamburg, taking into account the sides of the horizon	Nethod of V. N. Bogoslovskiy, taking into account the sides of the horizon and the time location
Heat gain from the sun, W	2 195	2 260	1 394	1 346

Conclusions. When determining the heat gain from solar radiation by methods that do not take into account the sides of the horizon and the time of day, the amount of heat gain is significantly greater than with their consideration (Table 3). Methods that are not based on taking into account the sides of the horizon are impractical to use in engineering calculations due to the primitive approach and, as a result, the "roughness" of determining the calculated values. They, as a rule, give inflated values by almost 2 times. On the contrary, the methods of V. N. Bogoslovskiy (accounting for the time of day) and P. Y. Hamburg, taking into account the sides of the horizon, give almost identical results (a difference of 48 watts), which proves the correctness of determining the calculated values. The ASHRAE technique has two advantages — it not only takes into account the solar factor of a particular glazing, but is also adapted to automated calculations in ANSYS FLUENT.

To calculate the total heat gain from solar radiation, we can recommend the method of P. Y. Hamburg [6], which is applicable for comparative evaluation engineering calculations due to its simplicity, in comparison with the method of V. N. Bogoslovskiy. V. N. Bogoslovskiy's more labor-intensive method (taking into account the time of day) can be recommended for automated calculations in Excel.

The analysis of the calculation results presented in Table 3 shows that the greatest value of heat gain for summer is from solar radiation and is 1,393.2 W. At an outdoor air velocity of 2.7 m/s, the transmission heat gain is the main one, equal to 914.1 W, operational heat gain is less important. The data obtained are necessary to determine the air flow and load on the selected heat exchange equipment. For the calculation, we select the highest value at an outdoor air velocity of 2.7 m/s.

When conducting model computer calculations and accounting for solar radiation, the ASHRAE technique is the most suitable one. It has two important advantages — it takes into account the solar factor in relation to a specific type of glazing and is adapted to automated calculations in ANSYS FLUENT.

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Analysis of occupational injuries at enterprises for processing and canning meat and meat food products

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*Introduction.*The article considers the problems and provides the analysis of industrial injuries at meat and meat food productsprocessing and canningenterprises, which have a certain sectoral specificity that affects the formation of working conditions and contributes to the emergence of industrial injuries.
Problem Statement. The aim of this study is to analyze occupational injuries, their causes and to propose appropriate measures to prevent injuries.
Theoretical Part. The initial information is the data of the statistical reporting of the Federal State Statistics Service on industrial casualties by type of activity – Processing and canning of meat and meat food products.
Conclusions. The results of the analysis show the existence of a problem of occupational injuries and the need to introduce and implement a number of measures aimed at improving working conditions and improving safety at work in order to prevent occupational injuries.

***Keywords*:** meat and meat food products processing and canning, occupational injuries, labor protection, occupational safety.

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Introduction. The difficulties of regulating safety of technological processes over the past few years have acquired a large-scale character. The number of accidents in industry, transport, and the agro-industrial complex remains stable, and industrial injuries, which are a negative factor in the economic and social development of the country, do not decrease [1].

At enterprises engaged in processing and canning meat and meat food products, working conditions, pronounced industry specifics, complexity and variety of technological processes, features of equipment operation are associated with a certain danger for workers [2]. Cases of injuries, as well as the death of workers, are noted in such areas of activity as the production of chilled meat, frozen offal, animal fats, offal unsuitable for human consumption, salted, boiled, smoked, dried and other meat, sausage products, etc. The specifics of working conditions differ in the qualitative and quantitative ratio of harmful and dangerous factors of the production sphere (physical, chemical and biological) and the labor process (severity and tension). Workers performing technological operations and implementing labor functions related to processing and canning meat are simultaneously exposed to several types of danger, the most common occupational injuries and diseases are disorders of the musculoskeletal system, skin and infectious diseases, hearing loss [3, 4].

Problem Statement. The objective of this study is to analyze occupational injuries based on data from the Federal State Statistics Service, calculate injury rates according to the generally accepted methods, and study the causes of injuries in the field of the activity under consideration by studying literary sources and proposing measures to prevent injuries.

Theoretical Part. Regular and widespread risk assessment (namely, a combination of the probability and frequency of physical injury or other harm to the health of employees) using the existing volume of statistical information and the signs of tasks being solved at enterprises of any form of ownership and type of activity makes it possible to develop measures to reduce the quantitative and qualitative component of accidents at work, as well as to improve labor safety and its conditions [5, 6]. In such cases, injury risk indicators are usually used, which include the frequency of accidents, the frequency of fatal accidents, the severity of occupational injuries [6]. To calculate these indicators, let us refer to the data of the Federal State Statistics Service on enterprises for processing and canning meat and meat food products for 2019-2020 (Table 1) [7].

Table 1

Information about victims at meat and meat food products processing and canning enterprises in 2019-2020

Indicator	Numeric data	
	2019	2020
Number of enterprises, units	852	800
of them ones without accidents	714	658
Average number of employees, people	196 476	190 634
Number of victims with disability for one working day or more and with a fatal outcome, people	327	273
fatal outcomes of them	8	8
Number of person-days of disability for victims with disability for one working day or more and with a fatal outcome	14 745	11 092
Number of people with an occupational disease determined in the reporting year, people	2	2
Spent on labor protection measures for the year, thousand rubles	2 202 935.7	3 184 875.9

Table 2 presents the calculation results of the injury rates for the years under review.

Table 2

Injury rates at meat and meat food products processing and canning enterprises for 2019-2020

Injury Rate / Coefficients	Period	
	2019	2020
Accident rate	1.66	1.43
Frequency of fatal accidents	0.041	0.042
Severity of occupational injuries	46.2	41.8

Based on the analysis of the data in Table 1 and Table 2 it can be noted that in general, for the period from 2019 to 2020, the total number of victims at enterprises with the type of activity in question is characterized by a decrease — from 327 to 273. However, to a greater extent, such changes are associated not with improving working conditions, but with a reduction in the number of enterprises and, consequently, a reduction in the number of employees. So, in 2019, the number of processing enterprises amounted to 852 units, and in 2020 — 800 units (due to the general trend towards a decrease in the number of small and medium-sized businesses in the country), the average number of employees during the period under review also decreased — from 196,476 to 190,634 people, and the number of victims decreased — from 327 to 273.

If we consider specific statistical data for a longer period (for example, over the last five years), then we should note a downward trend in both the number of enterprises as a whole and a decrease in the number of enterprises that did not have accidents (Fig. 1). The number of employees in the sector under consideration (both as a whole and affected) also tends to decrease. So, in 2016, with the number of employees 175,099, 309 people were injured, in 2017, with the number of employees 212,608, 363 people were injured, in 2018, with the number of employees 197,035, there were 308 people injured, in 2019, with the number of employees 196,476, 327 injured, in 2020, 273 out of 190,634 people were injured.

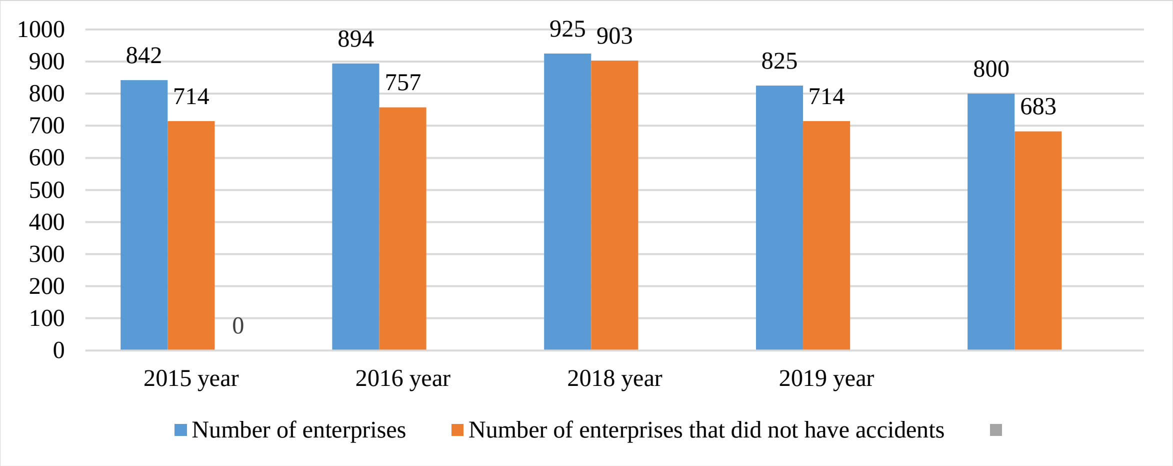

Fig. 1. The number of enterprises for meat and meat food products processing and canning from 2015 to 2020 as a whole and those that had no accidents

Also, the decrease in the total number of victims is associated with an increase in spending funds on labor protection measures, including the purchase of special shoes and clothing, personal protective equipment, organizational, technical, technological, sanitary and hygienic measures, as well as training of workers on labor protection issues. In 2019, 2,202,935.7 thousand rubles were spent on the above-mentioned activities at meat processing and canning enterprises, which averaged 11.2 thousand rubles per employee, and in 2020 3,184,875.9 thousand rubles (16.7 thousand rubles per employee). Figure 2 provides the ratio of such expenses in 2020 by groups

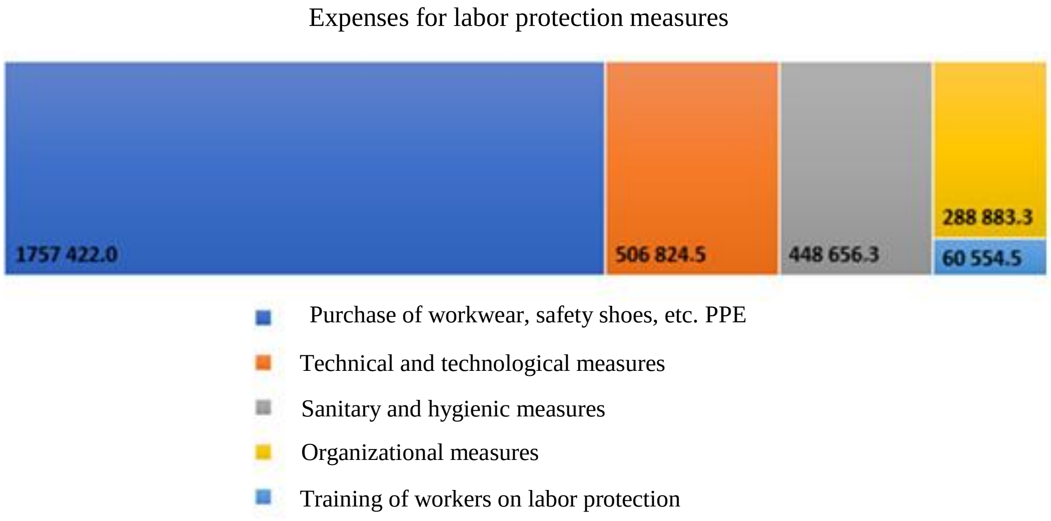

Fig. 2. Expenses for labor protection measures at enterprises for meat and meat food products processing and canning in 2020, thousand rubles

According to the number of researchers [5, 8], the main causes of injuries at enterprises for processing and canning meat and meat food products are unsatisfactory organization of work, imperfection of the technological process, wear and/or malfunction of technological equipment, shortcomings in the organization and conduct of training, training in the field of occupational safety, admission to the performance of labor functions of staff without training in safe working methods, shortage and/or non-use of personal and collective protective equipment, special clothing and footwear, auxiliary tools, the absence of flow charts for carrying out individual works and, as a result, non-compliance with non-hazardous work technology and technological process, weak labor and production discipline (including cases of alcohol, narcotic and other types of intoxication of employees), traffic accidents (including violations of traffic rules).

Such causes of occupational injuries at enterprises for processing and canning meat and meat food products should also be noted as the specificity of the "man — technological equipment — environment" system. The peculiarity of technological equipment during operation consists in the presence of mechanical, electrical, thermal hazards, noise, vibration, radiation, hazards caused by non-compliance with ergonomic requirements, as well as problematic automation, as a result of which a significant part of the stages of the technological process depends on skills, experience, human health, his/her training, reaction time, physical and mental state. The originality of such an environment is characterized by the presence of harmful and dangerous factors of biological nature, as well as hazardous and aggressive factors that determine the human condition, for example, the sight and smell of blood and internal organs of animals [9, 10]. Thus, during the implementation of labor and professional activities, the employees of the enterprises in question may have injuries associated with the operation of technological equipment and the implementation of the technological process, and injuries of a mental nature. In this regard, professional selection is important, taking into account the employee's ability to resist aggressive factors of the production environment.

Focusing on the relationship between industrial injuries and technological equipment at meat processing and canning enterprises, we note that often cases of injuries are caused by malfunction and wear of machines and mechanisms (such as saws, meat grinders, cutters, lifts, mincing machines, etc.), close contact of workers with dangerous production equipment or tools (for example, when working with knives) [11], imperfection of technological equipment (due to the absence or malfunction of protective devices on equipment, for example, on a machine for processing intestines, there are no devices that ensure safety of loading and unloading, pressure monitoring and control devices, for example, vacuum boilers, locks at power grinders and crushers, fences, for example, electric dehumidifiers, etc. emergency switches, for example, on the line of primary processing of poultry, etc.), non-compliance of the placement of technological equipment with safety and ergonomics requirements (for example, the discrepancy between the distance between the work places of boners and trimming workers, the lack of devices for storing hand knives during the operation of the machine operator for removing the skin from the fat, etc.), non-compliance with labor protection rules when working with technological equipment. The main types of injuries in the above cases are limb injuries, fractures, dislocations, burns, electric shocks, etc.

The causes of injuries at enterprises, including the type of activity under consideration, are also the organization of work production that does not meet the requirements, low level of equipment of workplaces and their maintenance in an inappropriate condition. The organization of the workplace involves equipping it with the necessary means and objects of labor and creating appropriate conditions to guarantee the safety of the work performed and determine the well-being, efficiency, productivity of the working person.

The unwillingness of the employers to introduce and improve the labor protection system, to revive the relevant services and to include labor protection specialists in the staff is the primary source of the causes of injuries at enterprises, and as a result there is no regular monitoring of compliance with labor protection legislation, the implementation of labor protection measures, safe behavior and compliance with the rules and requirements of labor protection by employees, including [12].

As the cause of occupational injuries, it is necessary to highlight the lack of a special assessment of working conditions at workplaces, production control over the implementation of sanitary norms, rules, hygienic standards and the implementation of sanitary and anti-epidemic measures. Due importance is not attached to the development and implementation of appropriate preventive measures; the actions of persons responsible for them are not controlled.

Conclusions. To improve the safety of workers of enterprises for processing and canning meat and meat food products, it is necessary to develop a set of organizational, technical and sanitary-hygienic measures aimed at injuries prevention, while the main objectives of such measures should be to increase the effectiveness of occupational safety training and assistance in the participation of employees of the organization in occupational safety activities, professional selection in terms of suitability in connection with the specifics of production, guarantee the safety of production equipment, processes, technology improvement, ensuring the safety of buildings, structures, premises, the territory of the enterprise by maintaining them in good condition, repair, replacement, etc. normalization and maintenance of sanitary and hygienic working conditions at optimal and acceptable levels by preventing excess of the established occupational safety standards and permissible levels of hazardous and harmful production factors, eliminating their sources, stabilizing work and improving the effectiveness of collective protection, providing workers with the necessary protective equipment not only in accordance with the current standard industry standards, but also in accordance with actual necessity, pragmatization of work and rest regimes, therapeutic and preventive maintenance and training in methods and techniques for first aid to victims, regular analysis of hazards and risk assessment arising from the peculiarities of the working environment and the organization of the labor process, assessment of working conditions, production control, planning measures to prevent and reduce the risks of injury and occupational safety measures.

When implementing such measures, their joint implementation by the company's managers, specialists in the field of labor protection and direct participants in the labor process is important. The implementation of measures to improve the working conditions and labor protection of employees will reduce, and in the future eliminate injuries at meat and meat food products processing and canning enterprises.

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On the issue of organizational problems of state fire supervision in connection with the entering into force of the federal law on state control (supervision) and municipal control in the Russian Federation

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Introduction. Due to the updating of the legislative framework, the possibility of introducing the so-called "seamless" interdepartmental processes in the field of fire control and supervision is considered. The paper shows how insufficiently well-regulated actions of departments can become a factor that reduces the efficiency of work in this area and hinders its development. The importance of Federal Law No. 248-FZ of July 31, 2020 "On State Control (Supervision) and Municipal Control in the Russian Federation" was noted. At the same time, significant difficulties of its practical application are recognized. With references to the sources, it is shown that, addressing this problem, scientists demonstrate either a global, enlarged approach, or, conversely, study particular cases within the borders of one region, in relation to a specific group of objects of fire control and supervision. The relevance of the presented work lies in the fact that the authors offer an adequate solution to universal organizational problems.

Problem Statement. The starting point in solving the tasks of this scientific work is the study of the text of Federal Law No. 248-FZ of July 31, 2020 "On State Control (Supervision) and Municipal Control in the Russian Federation". From the point of view of law enforcement practice, the authors had to evaluate innovations in the activities of the state fire supervision bodies of the Ministry of Emergency Situations of Russia, identify weaknesses if possible, make arguments in favor of organizational and, in particular, communication processes, identify ways to solve the problems.

Theoretical Part. The new document is considered as an element of the evolutionary process of state policy in the field of monitoring the compliance with mandatory requirements, including in the field of fire safety. The main imbalances that can potentially reduce the efficiency of the relevant departments of the Ministry of Emergency Situations have been identified. Thus, the Regulation on Fire Safety provides for the collection, clarification and annual updating of accounting information about the objects of supervision. At the same time, only the names of procedures are given in the document. There is no scheme of actions that links the object of supervision with such features of the subject (official) as: knowledge, experience, workload, Internet skills, computer or digital technology, technical and organizational availability of information resources. According to the statistics, the urgent need for appropriate adequate solutions is dictated by objective reasons. Constructive and relatively easy-to-implement measures to overcome the identified imbalances are indicated.

Conclusions. The results of scientific work presented in this article demonstrate the direction of further improvement of the professional activities of specialists in fire control and supervision, as well as the department as a whole. The results of the research suggest that at the present stage in Russia (and, in particular, in the Rostov region) the information base is sufficient to improve departmental processes. Two factors should be recognized as the main weaknesses of the system. This is clearly insufficient digitalization of departments and the lack of high-quality communications between departments of various levels and profiles.

***Keywords*:** state fire supervision, state control, risk-oriented approach.

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Introduction. Until a certain time, coordination of state and municipal control and supervision was a significant theoretical and applied difficulty [1–3]. Imbalances caused by the inability to build so-called "seamless" processes in the field of fire control and supervision were considered as a special case of the designated problem. Insufficiently well-regulated actions of departments at various levels could be a factor that reduces the efficiency of work in this area and hinders its development [4]. The necessary amendments to the current legislation were discussed in the scientific, professional and legislative environment [5, 6]. The result should have been a new regulation. This turned out to be the law defining the tasks of state and municipal control. It came into force in the summer of 2020 and marked a new stage in the development of the field of supervision (including firefighting), which can now focus on a single basic legislative act. At the same time, it is necessary to recognize significant practical difficulties that can become an obstacle to the growth of the effectiveness of the activity under consideration. It should be noted that, addressing this problem, scientists demonstrate either a global, enlarged approach, or, conversely, study particular cases within the borders of one region, in relation to a specific group of the controlled objects [7]. The relevance of the presented work lies in the fact that it offers a solution to universal organizational problems. On the one hand, they are faced by arbitrarily small fire and supervision departments. On the other hand, the processes under study are scaled and can be implemented at the federal level.

Problem Statement. The objectives of this scientific work are related to the study of the text of Federal Law No. 248-FZ of July 31, 2020 "On State Control (Supervision) and Municipal Control in the Russian Federation". In this document, the authors of the presented article are primarily interested in innovations in the activities of the state fire supervision bodies of the Ministry of Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM) of the Russian Federation. Scientific research in this direction allowed us to solve the difficulties of applying some provisions and identify possible solutions.

Theoretical Part. On July 31, 2020, Federal Law No. 248-FZ "On State Control (Supervision) and Municipal Control in the Russian Federation"[1] came into force. The document should be considered as an element of the evolution of state policy in the field of monitoring the compliance with mandatory requirements. In particular, the legislative act under consideration develops the provisions of federal laws on the protection of the rights of legal entities and individual entrepreneurs in the course of state control (supervision) and municipal control No. 134-FZ of 08.08.2001 and No. 294-FZ of 26.12.2008.

As legislatively proposed innovations, the following should be noted:

— new supervisory procedures;

— emphasizing the importance of conscientious compliance with the requirements;

— orientation towards the introduction of modern information technologies, that is, digitalization of control (supervisory) activities.

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[1] Federal Law No. 248-FZ of July 31, 2020 "On State Control (Supervision) and Municipal Control in the Russian Federation". State Duma; Federation Council. Collection of Legislative Acts of the Russian Federation of August 3, 2020 No. 31. Part I. Art. 5007.

Within the framework of the document under study, the Regulation on Federal state fire supervision has been updated[2]. One of the conditions for the effectiveness of such activities is timely and complete accounting of objects supervised by the Ministry of Emergency Situations of Russia.

For these purposes, the Regulation provides for the collection, clarification and annual updating of accounting information about the objects of supervision. It should be clarified that in this case, the names of procedures are established. We are not talking about a scheme of actions that links the object of supervision with such features of the subject (official) as:

- professional knowledge,
- work experience in public authorities or local self-government,
- official workload,
- skills in working on the Internet, with a computer or digital equipment,
- technical and organizational availability of all necessary information resources.

In other words, an ordinary employee of the territorial department should have a working scheme of operational and high-quality information interactions at his disposal. Let us give an example. The specialist must know exactly where and how to send a request for information on the accounting of objects of supervision. Moreover, the communication system should exclude any ambiguity, which can subsequently be interpreted as the withdrawal of objects from accounting and supervision. In this case, it is unacceptable to offer the contractor an indefinite or unclosed list of sources of information.

The current version of the Regulation has not been finalized in this sense.

Let us mention another obvious weak point of the current version of the document. Its authors assume that a person will process and analyze incoming data, the volume of which is enormous.

An example may be one of the aspects of applying a risk-based approach. Thus, even those land plots without any buildings and structures should be classified as risk categories. Therefore, these objects should to be taken into account and monitored— including planned control (supervisory) measures. In accordance with the current procedure, such sites should certainly be assigned a moderate risk category[3].

According to the Federal Service for State Registration, Cadastre and Cartography, in November 2021, 149,936 land plots were registered on the territory of Rostov-on-Don, excluding land on which surveying work was not carried out. On the scale of the Rostov region, we are talking about 2,124,923 plots and 3,011,596 capital construction objects[4].

At the same time, the staff size of the department of supervision and preventive work in Rostov-on-Don is 45 people. It is obvious that they cannot analyze the simultaneously received data of such volume and compare them with the already available information. Or they will have to do only this and stop all the other core activities of the organization. Conditionally, we will take 1 minute for the average processing time of information about one land plot. This means that 6.94 working days of continuous work of the entire department will be required to process all the data.

Thus, the total state supervision provided for by law is negated by the lack of human, time and other resources.

The situation is similar with the control (supervisory) measures with such a number of objects of supervision. Let us consider an example with a site classified as a moderate risk, due to which planned control (supervisory) measures are carried out on it no more than once every 6 years. How in this case will it be necessary to treat the situation if violations of fire safety requirements in this area will cause harm to human health or his death? It is quite obvious that in order to assess the completeness of the implementation of state supervision, supervisory or investigative authorities can use conditional reasonable periods of events. Negative examples in this case will be clearly inadequate upper limits of terms (for example, decades). We should also note: the performers, of course, should be disciplined by the idea that in the ranks of the fire supervision authorities the guilty person will always be found.

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[2] Regulation on Federal State Fire Supervision No. 290 of April 12, 2012. Government of the Russian Federation. Collection of Legislative Acts of the Russian Federation No. 17 of April 23, 2012. Part III. Art. 1964.

[3] Regulation on Federal State Fire Supervision No. 290 dated April 12, 2012. Government of the Russian Federation. Collection of Legislative Acts of the Russian Federation of April 23, 2012 No. 17. No. 27. Part III. Art. 5403.

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The most effective solution is to optimize the number of objects of supervisory activity by unconditionally assigning land plots of the considered type to a low risk category and eliminating the need to carry out planned control (supervisory) measures in relation to them.

Another way to solve the problem is to increase the risk category if there are confirmed data on violations of fire safety requirements on undeveloped (empty) land plots and (or) in connection with fires that occurred on them.

In addition, it is necessary to legislatively approve the annual provision of accounting information about objects of protection from the Federal Service for State Registration, Cadastre and Cartography, which records and registers land plots and capital buildings. In this case, the data must be received in the "no request" mode. That is, the supervisory authority should not initiate the transfer of information; it will be guaranteed to receive them in any case at a set time.

Conclusions. Prompt resolution of the theoretical and law enforcement ambiguity of the described innovative legislation will avoid discrediting the control and supervision bodies, as well as the Ministry of Emergency Situations of Russia. In addition, such an approach will improve the organizational and psychological conditions of the professional activity of officials, provide them with the opportunity to perform their duties in a timely manner and in full.

The results of scientific work presented in this article demonstrate the direction of further improvement of the work of specialists in fire control and supervision, as well as the department as a whole. The results of the research suggest that at the present stage in Russia (and, in particular, in the Rostov region) there is an information base sufficient to increase the effectiveness of fire control and supervision. Two factors should be recognized as the main weaknesses of the system. The first is the level of digitalization of departments and the so-called digital competencies of a number of specialists. The second is the lack of direct, clear and unambiguous communications between departments of various levels and profiles.

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Dependence of death and injury of people in fires on the duration of fires

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Introduction. The effectiveness of the actions of the fire protection units depends on their readiness for action, that is, on the state of the forces and means of the station and the ability to perform the main task within the existing tactical capabilities.

Problem Statement. When developing mathematical models of the operational activities of the fire department, its effectiveness and the assessment of the readiness of fire protection units to extinguish fires, it is important to study the dependence of the death of people in fires on the duration of the fire. This study is devoted to this task.

Theoretical Part. The distribution of fires in the Russian Federation for 2016-2020 by their duration and the dependence of deaths and injuries of people in fires, as well as their ratio to the duration of fires in the Russian Federation for 2016-2020, is studied. It is shown that the average duration of the fire during the studied period was 26 minutes, the median value of the distribution was 18 minutes. The dependences of deaths and injuries of people in fires on the duration of fires are approximated by a logarithmic function. When the duration of the fire is up to 26 minutes. the ratio of the number of people injured in fires to those killed decreases exponentially, but remains stable in the rest of the time range.

Conclusions. It is concluded that it is necessary to increase the readiness of the fire department for actions to extinguish fires and rescue people, which includes the development of an information and analytical model of the operational activities of the fire department.

Keywords: fire, duration, death, injury, efficiency.

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Introduction. In accordance with the Field Manual of fire departments, "fire extinguishing is an action aimed at saving people, property and eliminating fires" [1]. The duration of a fire is considered to be the time from the moment of its occurrence until the complete elimination of fire [2]. In this work, the duration of a fire is considered to be the interval between the time of detection and the time of elimination of open fire. Many scientific studies have studied various stages of the development and extinguishing of fires, as well as the dependence of the death of people in fires on the actions of fire departments [3–8].

The effectiveness of the actions of fire departments depends on their combat readiness, that is, on the state of the forces and means of the garrison and the ability to perform the main task within the available tactical capabilities [1].

Problem Statement. When developing mathematical models of operational activities of fire protection, its effectiveness and assessment of the readiness of fire departments to extinguish fires, it is important to study the dependence of the death of people in fires on their duration. This study is devoted to this task.

Theoretical Part. The information is calculated from electronic databases of accounting for fires and their consequences [9]. Figure 1 shows the distribution of fires for 2016-2020 by their duration, which were extinguished by the territorial fire and rescue departments of the Federal Fire Service of the State Fire Service

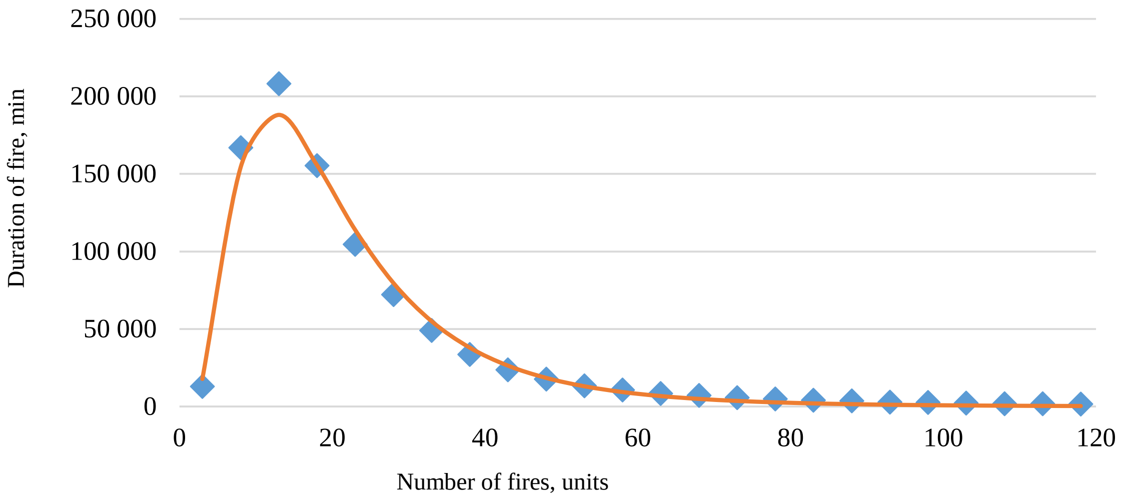

Fig. 1. Distribution of fires in the Russian Federation for 2016-2020 by their duration
The curve is lognormal distribution

The average duration of the fire during the studied period was 26 minutes. However, given the pronounced asymmetry of the distribution (the asymmetry coefficient is 2.5); it is advisable to use the median of the distribution, which is 18 minutes, to estimate the mathematical expectation. The duration of 69% of fires did not exceed 30 minutes. This distribution is well described by the lognormal function

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} \exp\left(\frac{-(\ln t - \mu)^2}{2\sigma^2}\right), \quad (1)$$

where t — the duration of the fire, min; parameters μ = 2.9 and σ = 0.64. The coefficient of determination is $R^2 = 0.99$.

Figure 2 shows the dependence of the death of people in fires on the duration of fires.

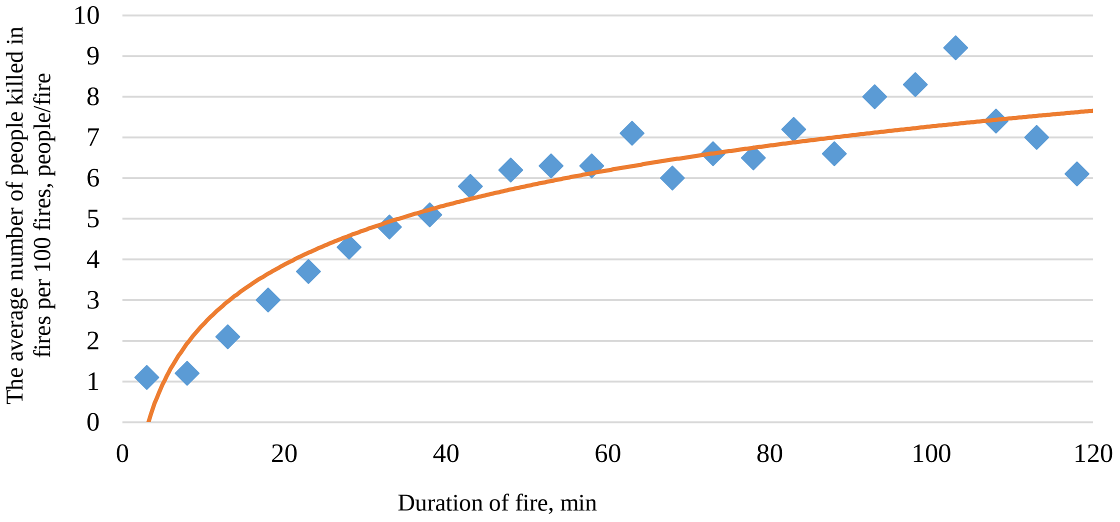

Fig. 2. Dependence of the death of people in fires on the duration of fires in the Russian Federation for 2016-2020

The curve is logarithmic function
The resulting dependence is well approximated by the logarithmic function

$$h(t) = a \ln t + \ b(2)$$

with parameters a = 2.113 and b = – 2.461. The coefficient of determination is $R^2 = 0.86$.

However, it is necessary to treat the presented data with caution, since it is unclear when the critical duration of the fire occurred and at what point people died [2, 4]. In the same way, it is necessary to treat the dependence of injury to people in fires on the duration of fires, shown in Fig. 3.

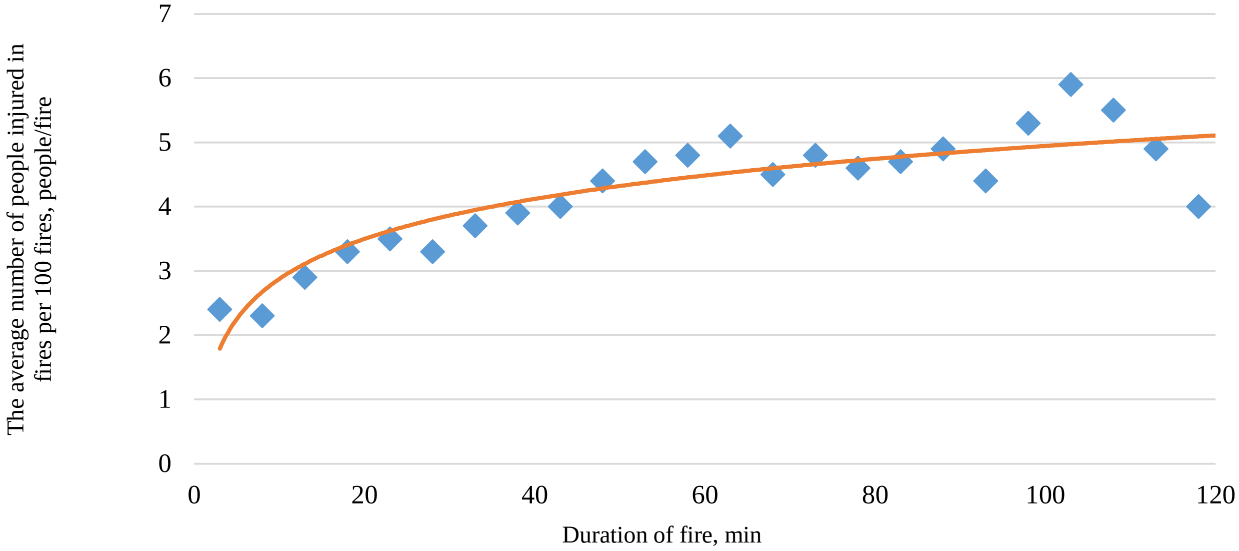

Fig. 3. Dependence of injury to people in fires on the duration of fires in the Russian Federation for 2016-2020. The curve is a logarithmic function

The obtained dependence is also well approximated by the logarithmic function (2) with parameters *a* = 0.899 and *b* = 0.804. The coefficient of determination is $R^2 = 0.81$.

In recent studies, an indicator of "the ratio of the number of people injured in fires to the dead" is singled out separately [10-13]. This indicator characterizes the level of development of fire protection measures (fire alarm systems, primary fire extinguishing means, etc.), as well as fire protection actions to extinguish fires and rescue people, neutralizing fire hazards, reducing the number of people killed in fires. Figure 4 shows the dependence of the ratio of the number of people injured in fires to those killed on the duration of fires. This dependence is described by the function:

$$g(t) = \begin{cases} A\exp(-bt), & t \le 25\, min \\ 0.71, & t > 25\, min \end{cases} \tag{3}$$

with parameters *A* = 2.69, *b* = 0.048. The coefficient of determination is $R^2 = 0.99$.

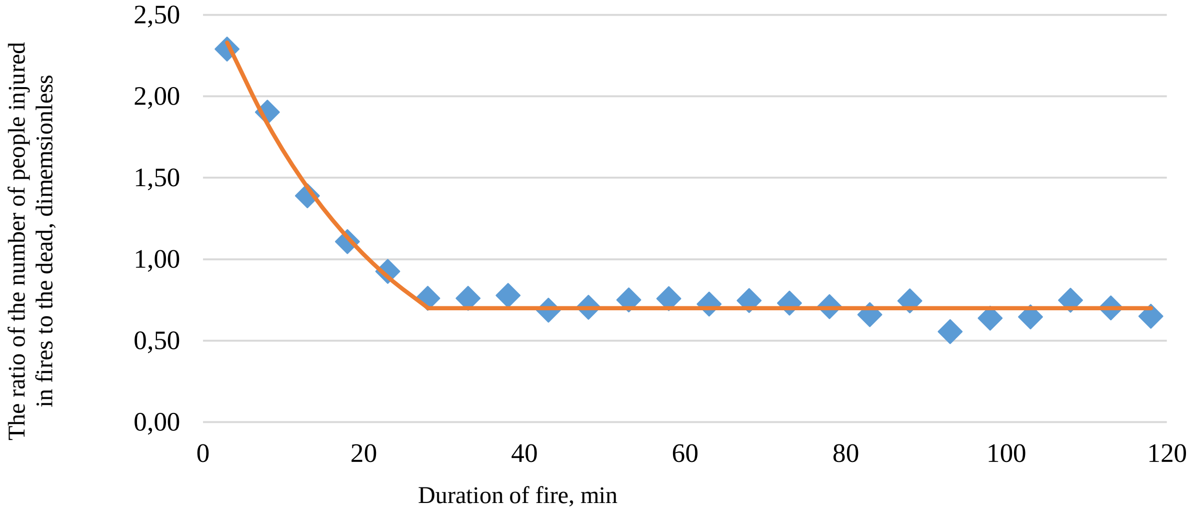

Fig. 4. Dependence of the ratio of the number of people injured in fires to those killed on the duration of fires in the Russian Federation for 2016-2020. The curve is the dependence described by formula (3)

It should be noted that a significant result is observed from the actions of the fire department to rescue people only if the duration of the fire does not exceed 25 minutes, and the effectiveness of the actions is described by a linear function with a negative slope coefficient. That is, the shorter the duration of the fire, the more effective the actions of the fire department to rescue people. With fire duration of 26 minutes or more, rescue actions reach a constant level (the slope coefficient of the approximating function is close to 0); the average ratio of the number of people injured in fires to those killed is 0.71.

For example, Figure 5 shows the values of the ratio of the number of people injured in fires to those killed in a number of foreign countries in 2018 [14].

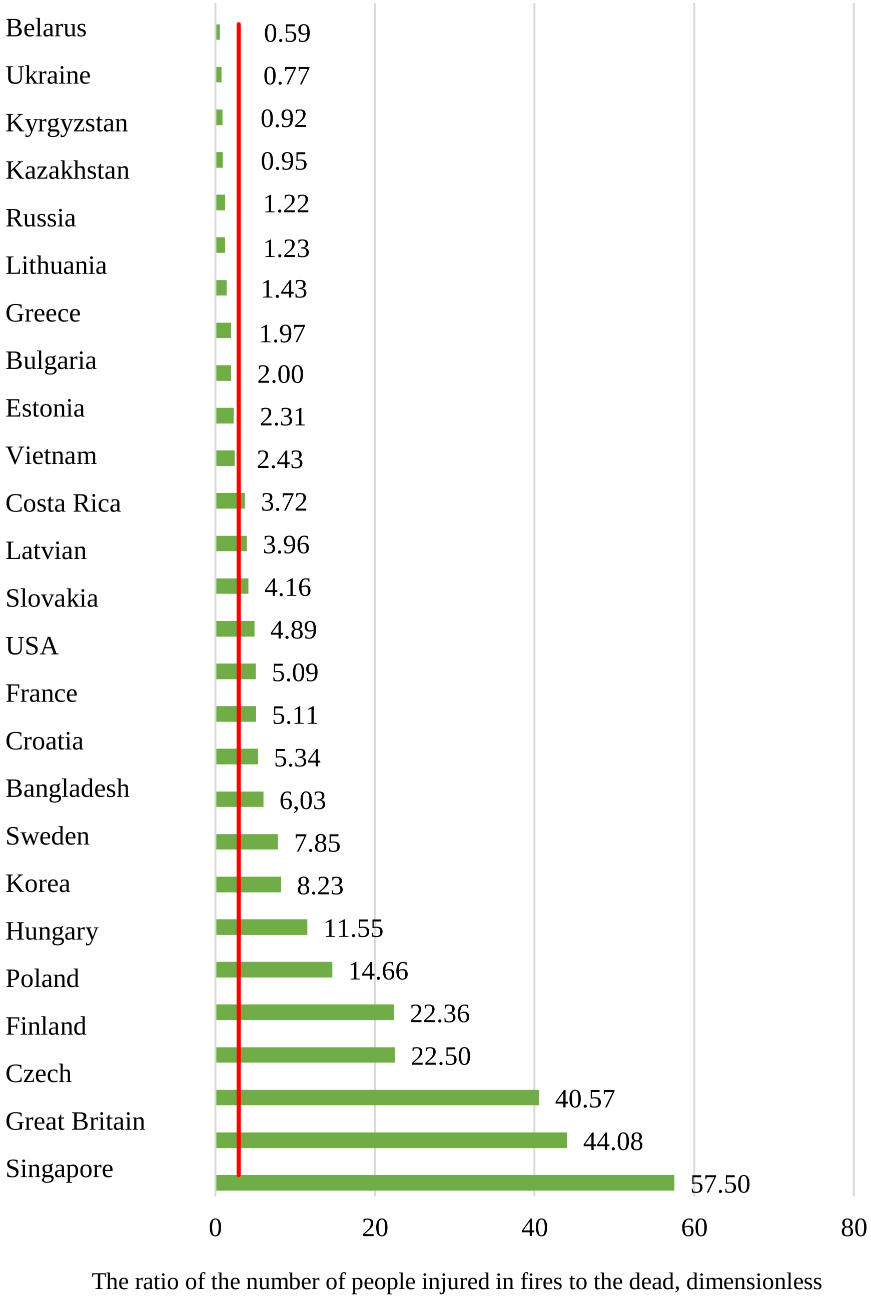

Fig. 5. The ratio of the number of people injured in fires to those killed in 2018 in some countries of the world

As it can be seen from Fig. 5, the Russian Federation, with an indicator of 1.22 people injured in fires per 1 person killed, occupies one of the last places in the list of countries. The situation on this indicator is worse only in Belarus, Ukraine, Kyrgyzstan and Kazakhstan. The red vertical line corresponds to the average value of the indicator under consideration for all the countries listed (2.93).

The data obtained can be explained by a number of factors: climatic, socio-economic conditions, the activities of fire departments, personnel qualifications, etc.

Conclusions. The presented data indicate a large reserve among fire departments of the Russian Federation in terms of increasing readiness for fire extinguishing and rescue operations, which include improving the tactical capabilities of fire departments, fire equipment, extinguishing agents, the creation of new fire departments taking into account the identified patterns.

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Organizational and managerial issues of improving the fire safety of the protected objects

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Introduction. The paper considers the issues of modernization in the field of fire safety. It is noted that insufficient attention is paid to the tasks of fire safety management of the protected objects, and this negatively affects the overall level of security in the regions. The most relevant and effective method of improving the fire safety of the protected objects is the active introduction of robotics and artificial intelligence.

Problem Statement. The objectives of this study are to develop proposals to improve fire prevention and fire protection systems, as well as to create a set of measures aimed at ensuring fire safety.

Theoretical Part. The works of scientists on the topic of this study are used as basic information. The system of fire safety organization, legal regulation and state measures in the field of fire safety have been studied.

Conclusions. The results of the study can be used in practice to ensure the fire safety of the protected objects, as well as for further scientific research.

Keywords: fire safety, objects of protection, robotics, artificial intelligence.

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Introduction. The development of complex technologies, the activities of large industries and urbanization significantly increase fire danger of the protected objects. The occurrence of fires in large administrative, sports and educational complexes with a significant number of people can result in injuries and casualties.

The factors that arise as a result of a fire exceed other high-risk incidents in terms of danger of negative consequences. Therefore, it is necessary to pay special attention to such tasks as creating conditions for preventing fires, successfully extinguishing them, and timely evacuation of people. This will significantly reduce the damage from fires and the number of victims.

Problem Statement. The current level of development of digital technologies allows us to constantly improve the efficiency of fire robots. This technique, along with traditional approaches, has proven itself well in emergencies. In the field of automatic fire fighting equipment, the use of robotized installations is set by law. As for mobile robotized technology, the issue requires serious improvement. Based on scientific materials, it is necessary to formulate proposals for improving fire safety of the facilities.

Thus, V. V. Kiselev considers it optimal to ensure fire safety through the introduction of robotics[1], A. Lazarev — with the help of artificial intelligence (AI)[2].

Theoretical Part. Automatic fire fighting equipment can significantly reduce the number of victims and damage from fires. Automatic fire fighting systems are a necessary component of fire protection of any object. This is especially true for objects with crowds of people.

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Another element of developing fire technologies is fire robots. They are already in service with the fire department. Their purpose is to facilitate the work in extinguishing fires and eliminating the consequences of emergencies, to ensure the safety of people at enterprises with increased radiation and chemical risks[3].

As a rule, fire robots are made on the basis of wheeled or tracked vehicles and extinguish fire with water and foam. Fire robots of various modifications are distinguished by special elements that determine the functionality. The main distinguishing feature of the fire robot is the possibility of remote control. The software allows you to set fire extinguishing parameters, ensuring high efficiency of fire fighting. This is the main function of the fire robot, but it can also transmit data from the work site. To do this, the car is equipped with video cameras and infrared scanners. Computer processing of the video image allows you not only to observe the process of extinguishing the fire, but also to determine the parameters necessary for greater extinguishing efficiency: the area of the fire, the location of the fire source. The operator determines the trajectory of the robot.

Another advantage of robotic fire extinguishing means is the possibility of round-the-clock use for monitoring the protected object. If a fire is detected, the robot can perform its extinguishing function without an operator's command. Conventionally, fire robots can be divided into three types:

1) android robotic systems,

2) mobile fire robots,

3) stationary automated installations.

In Russian practice, the RSS fire robot is successfully operated, which can transmit video to the operator's screen. It extinguishes the fire with a compact jet of water, foam or powder. Such equipment is used in places of mass gathering and enclosed spaces: tunnels, storage facilities, etc. [1].

It is also worth noting the mobile fire-fighting robotic complex of the MRK-RP light class. Its brief description can be presented as follows: a set of mechanisms and devices for eliminating the consequences of accidents is installed on the tracked chassis, if there are explosive objects in the accident zone or there is a risk of harmful substances being released. The main working tool of such a robot is a manipulator. The electric drive expands the scope of its application [2].

The country also produced heavy robots — "El-4" and "El-10". They were mounted on a tracked chassis, equipped with fire extinguishing equipment and containers with fire extinguishing agent. The main purpose of such equipment is to work in terms of radiation exposure. The disadvantage is low mobility[4].

Let us move on to the use of artificial intelligence in the field of fire safety. In this field, AI is mainly used for:

1) processing an array of information when planning inspections,

2) object surveys,

3) monitoring the Internet and social networks,

4) monitoring of objects and territories of settlements.

In the first case, we are talking about establishing the facts of re-inclusion of objects in the annual inspection plans. In addition, unplanned objects and expired inspection periods are identified. The AI toolkit allows you to exclude other planning errors, including those of a technical nature [3]. You can configure the AI solution in such a way that it calculates the time of inspections, distributes it between the supervisory authorities and at the same time takes into account data on supervision of small businesses, microenterprises, branch network.

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In the second case, the following are involved:

— robotic equipment (wheeled or tracked mechanisms, as well as quadrocopters),

— wearable means,

— connection to the object's video surveillance systems,

— combinations of the listed solutions[5].

The functions that AI implements when examining objects are described below.

1. Application of technical measurement tools, including measurements of:

a) geometric dimensions of objects, escape routes, exits, distances;

b) illumination of premises;

c) noise pressure;

d) pressure parameters generated by smoke removal systems and (or) low air in case of fire;

e) temperature of objects, as well as wires, cables, etc.

2. Analysis of materials, including:

a) results of control and observation;

b) administrative documents;

c) projects (section of fire prevention measures) in comparison with regulatory legal acts and taking into account their relevance;

d) the project (section of fire-fighting measures) in comparison with the actual state of affairs;

e) characteristics of the object of supervision and their comparison with regulatory legal acts;

f) placement of evacuation plans, signs, fire safety signs, etc.

3. Monitoring of visits to premises according to the plan of the building (structure).

4. Scanning the actual state of affairs at the facility and calculating the individual (social) fire risk based on the results of the site visit.

5. Photo, video, audio recording

The implementation of the third direction of application of AI technologies makes it possible to use big data to identify objects of supervision[6].

The fourth direction involves monitoring using the satellite technology and outdoor video cameras. Let us list some of its tasks:

— to detect fire-hazardous objects and garbage,

— to locate the building of bonfires,

— to control the placement of vehicles and maintenance of fire hydrants.

Monitoring at the protected facilities will allow you not only to identify violations of fire safety requirements, but also to exclude the cases of false triggering of automatic fire alarms and prevent costly and unsuccessful response to them by fire departments.

Conclusions. This paper provides a brief analysis of decisions and actions aimed at modernizing fire safety of the protected facilities.

Currently, the main task facing the creators of fire robotics is to increase the level of autonomy of machines.

Modern development of technological processes should stimulate the creation of new intelligent solutions in the field of fire safety. That is why fire robotics is constantly improved and is increasingly used in the work of fire and rescue departments. This makes it possible to reduce the professional risks of firefighters and increase the efficiency of their work [4].

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Contribution of the authors

A. S. Netrebin, V. A. Bokova —formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formulation of conclusions; D. V. Totskiy — scientific supervision, analysis of research results, revision of the text, correction of the conclusions.

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Express method of assessment of compliance of the object of supervision with fire safety requirements

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Introduction. The paper considers the new requirements for the activities of the state fire supervision bodies. The ways of solving the problems arising during the implementation of these innovations are given. One of such solutions is the developed by the authors algorithm of the express method for assessing the compliance of the object of supervision with fire safety requirements. The article analyzes the work of inspectors of the state fire supervision during inspections of low-rise retail facilities of small area, taking into account the time spent on them, and the work of the inspector using a new express method of conducting inspections.

Problem Statement. The purpose of the study is to increase the efficiency of managerial decision-making in ensuring fire safety based on the criterion of "fire risk", taking into account the minimum fire safety requirements determined by the calculation.

Conclusions. The developed algorithm for supporting managerial decision-making on the compliance of the protection of commercial facilities with fire safety requirements will allow inspectors of the state fire supervision during inspections to assess the existence of a threat to human life and health and decide on further actions depending on the presence or absence of this threat.

Keywords: state fire supervision, state control, risk-oriented approach.

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Introduction. A number of regulatory legal acts of the Russian Federation and the Ministry of Emergency Situations of Russia have entered into force, which, in particular, relate to the organization of the work of the system of supervisory bodies of the Ministry of Emergency Situations of the Russian Federation. In those of them that relate to a risk-based approach to the inspections of buildings and structures for the compliance with fire safety requirements, there are no criteria for the time spent on conducting inspections, there is no definition of the staff size of structural units of supervisory activities, and also there is no possibility of reducing the burden on the subjects of supervision and minimizing mandatory fire safety requirements, which can only be determined by scientifically based methods.

Problem Statement. In the course of the research work, two algorithms for supporting management decisions in the actions of state fire supervision were compared using the example of small-area and low-rise retail facilities located in the Rostov region, taking into account the risk-oriented model of control and supervisory activities of the Ministry of Emergency Situations of Russia, that is, the existing algorithm, and the proposed algorithm based on the express method of assessing the compliance of the object of supervision with the fire safety requirements. Thus, the work of the state fire supervision inspectors was analyzed when conducting inspections of small-area and low-rise retail facilities for the time spent on them, and the work of the inspector with the proposed express method of conducting inspections. The analysis showed that the developed algorithm for supporting managerial decision-making on the compliance of commercial facilities with fire safety requirements allows inspectors of the state fire supervision service to assess the presence of a threat to human life and health during field inspections and decide on further actions depending on the presence or absence of this threat and save time spent on conducting inspections according to the existing algorithm and the algorithm proposed in the research work.

Analysis of the existing algorithm if there is no fire risk assessment at the facility. When during the inspection at the facility the federal state fire supervision authorities reveal that the fire risk assessment was not carried out there, it means that there is a violation of Article 5 [1], which states that a fire safety system should be developed in each building. One of its main goals is to ensure the safety of people; this system should exclude the possibility of exceeding the required fire risk value.

Also, in accordance with Article 6 [1], fire safety is ensured if:

— the requirements of technical regulations are fully met, and the fire risk value does not exceed the required one;

— the requirements of technical regulations have been fully complied with, and the voluntary requirements specified in regulatory documents have been met.

It is worth noting that in accordance with Part 3 of Article 4 [1], national standards and codes of rules as well as other documents belong to regulatory documents [2, 3]. These documents also include Order of the Ministry of Emergency Situations of the Russian Federation No. 382 of June 30, 2009 "On approval of the methodology for determining the calculated values of fire risk in buildings, structures and constructions of various functional fire hazard classes" [4].

According to the above two conditions, it can be concluded that it is necessary to perform the calculation of evacuation and the calculation of the occurrence of fire hazards in any case (either as part of the risk calculation in accordance with [3], or as part of the calculation of the level of fire safety of people in accordance with the order of the Ministry of Emergency Situations [4], which is the voluntary standard). This document states that in each building, volumetric and planning solutions should be such that people can evacuate in the case of a fire before the onset of dangerous factors.

It should be noted that if a fire risk assessment has not been carried out, then this is a violation of Article 53 [1], which states that all buildings must be designed and constructed in such a way that their volumetric and planning solutions, as well as the design of evacuation exits and paths ensure safe evacuation of people in case of fire.

In accordance with Article 89 [1], every building must have escape routes and evacuation exits that will ensure safe evacuation of people in case of fire. And in the same article it is said that it is necessary to provide for the calculation of escape routes and evacuation exits.

Based on the above, it should be emphasized that the confirmation of the safe evacuation of people at the facility should be in any case (either through the calculation of fire risk or through the calculation of the level of fire safety of people).

Analysis of the existing algorithm if there is a fire risk assessment at the facility. If during the inspection by the federal state fire supervision authorities of the protected objects it was revealed that the calculation of fire risk assessment was carried out, the layout and arrangement of technological equipment correspond to the project and risk calculation, then it can be concluded that the object meets the fire safety requirements.

But if the layout or arrangement of technological equipment and, accordingly, the configuration of escape routes have changed, then in this case the inspector decides not to accept the existing calculation and requires recalculating of the fire risk. The recalculation of fire risk takes a lot of time and brings losses to the owner in the form of lost profits.

In this case, it is necessary to apply an express method, with the help of which it is possible to determine in a short time the possibility of safe evacuation of people before the onset of the maximum permissible values of fire hazards. This method should be simple, do not require high qualifications, powerful computer programs and lengthy calculations. The users of this method may have only basic school knowledge and a small portable electronic computing device (smartphone, tablet, engineering calculator).

The analysis of the existing algorithm for making managerial decisions on the compliance of commercial protection facilities with the fire safety requirements during control measures by the state fire supervision authorities of the Rostov region has showed that there is no fire risk calculation at most facilities (86.4%), and at those facilities where the fire risk calculation was carried out, it usually does not correspond to the actual layout of the facility or the configuration of evacuation routes and the arrangement of technological equipment.

Therefore, it is necessary to develop a new algorithm to support managerial decision-making on the compliance of commercial protected facilities with fire safety requirements when carrying out control measures by the state fire supervision authorities of the Rostov region, which should take into account the risk-oriented model of control and supervisory activities of the Ministry of Emergency Situations of Russia and which would allow the inspectors of the State Fire Control Service to assess the threat to life and health of people in the field.

Development of an algorithm if there is a fire risk assessment at the facility. Let us consider a situation when a fire risk calculation is carried out at a protected facility. If there is a fire risk calculation, the inspector of the federal state fire supervision is obliged to check the correctness of the initial data taken in the calculation, whether they coincide with the actual situation at the facility or not.

Quite a lot of parameters and values are involved in the calculation of fire risk.

Since most commercial objects are rented out, we will consider these objects.

In commercial buildings, the inspector needs to check:

— the frequency of fires in the building during the year;

— the compliance of the automatic firefighting system with the requirements of the regulatory documents on fire safety;

— the probability of the presence of people in the building;

— the probability of evacuation;

— the compliance of the fire alarm system with the requirements of the regulatory documents on fire safety;

— the compliance of the fire warning system and evacuation management with the requirements of regulatory documents on fire safety;

— the compliance of the smoke protection system with the requirements of regulatory documents on fire safety.

It will not be difficult to check the frequency of fires, the availability of fire protection systems, and the probability of presence of people in the building. The greatest difficulty is, as a rule, checking the probability of evacuation.

As a result of numerous calculations, it was found that the minimum width of evacuation routes and evacuation exits in commercial buildings and premises should be at least one meter. This is due to the fact that these buildings and premises can accommodate low-mobility groups of the population, including those with two additional supports. The width of such a person with supports is 0.9 meters. Accordingly, the developed express method can be applied only to rooms with a width of escape routes and a width of evacuation exits of at least one meter. Therefore, it is necessary to check from the array of initial data only the probability of evacuation and the arrangement of technological equipment (trade racks), and, accordingly, the evacuation routes associated with this arrangement.

If the actual arrangement of the equipment corresponds to the one in the calculated evacuation schemes, then it can be concluded that the fire risk calculation meets the fire safety requirements.

If the actual arrangement of the equipment does not correspond to the one in the calculated evacuation schemes, then the inspector needs to find out whether there is a threat to human life and health. In this case, the express method developed by the authors of the article will help him. This method will serve as an indicator that will tell you how to proceed.

To do this, the inspector needs a portable computing device on which the program with this express method will be installed.

Below there is a set of actions that the inspector needs to perform in order to assess the threat to life and health of people in case of fire evacuation:

— to find out the height and area of the room. This can be done by measurements using a laser tape measure;

— in the calculation program, to select a formula for determining the occurrence of fire hazards depending on the height of the room;

— to enter the area of the room into the formula for determining the time of occurrence of fire hazards (the required evacuation time) and to get this time (T required);

— to enter the area of the room into the formula for determining the maximum permissible length of the evacuation path from the most remote point of the room to the evacuation exit and to get this length (L maximum permissible);

— to measure the maximum length of the rack in the room and to subtract from the maximum permissible length of the evacuation path (L maximum permissible) this length of the rack;

— to measure with a laser tape measure the actual length of the escape route from the most remote point of the room to the evacuation exit (L actual);

— to compare the actual length of the escape route and the required maximum permissible length of the escape route.

If the actual length is less than the required one, then the condition of safe evacuation is fulfilled and there is no threat to human life and health (L actual < L maximum permissible — corresponds), if the actual length is greater than the required one, then the condition of safe evacuation is not fulfilled and there is a threat to human life and health (L actual > L maximum permissible — does not correspond).

Next, the inspector needs to decide how to proceed based on the conclusions obtained by the express method.

If, according to the results of the express method, it is revealed that there is no threat to the life and health of people, then the inspector decides to make a requirement to recalculate fire risks in accordance with the new arrangement of technological equipment. And the owner then chooses the organization that will perform this recalculation or does it himself.

If, according to the results of the express method, it is revealed that there is a threat to the life and health of people, then the inspector decides to send the calculation of fire risk for examination to the fire testing laboratory.

The fire testing laboratory issues a conclusion on whether there is a threat to human life and health in accordance with the new arrangement of technological equipment.

If the conclusion of the fire testing laboratory indicates that, in accordance with the new arrangement of equipment, there is no threat to human life and health, that is, people will have time to evacuate before the onset of fire hazards, then the inspector decides to make a risk recalculation requirement in the assignment.

If the conclusion of the fire testing laboratory indicates that, in accordance with the new arrangement of equipment, there is a threat to human life and health, that is, people will not have time to evacuate before the onset of fire hazards, then the inspector decides to send the case to the court to suspend the activities of the inspected object.

Development of an algorithm if there is no fire risk assessment at the facility. Let us consider a situation when the fire risk calculation has not been carried out at the protected facility. If there is no fire risk calculation at the inspected facility, this means that it is necessary to check this facility according to the regulatory voluntary documents: codes of rules, national standards and others.

If, according to the results of the inspection, it is revealed that the requirements of the regulatory voluntary documents are fully met at the facility, it can be concluded that the facility meets the fire safety requirements.

If, according to the results of the inspection, it is revealed that the requirements of the regulatory voluntary documents are not fully met, then the inspector, in order to understand what to do next, needs to identify whether there is a threat to people's life and health or not. Since the standard fire safety requirements in the codes of regulations and national standards do not take into account the fire hazards, it is necessary to use the express method to assess this threat. According to the algorithm specified above, the inspector assesses the threat to people in case of fire.

If, according to the results of the express method, the absence of a threat is revealed, then the inspector decides to include into the assignment the requirements for the elimination of violations of the regulatory voluntary documents. There are no grounds for suspending this facility. If, according to the results of the express method, the presence of a threat is revealed, the inspector decides to transfer the case to the test fire laboratory for a full study and identification of a threat to human life and health based on the methodology approved by [3].

The fire testing laboratory, after the conducted research, indicates in its assignment the presence or absence of a threat to people. In the absence of a threat, the inspector decides to include requirements for compliance with the rules and national standards in the assignment. If there is a threat, the inspector decides to send the case to the court to suspend the activities of the facility.

Figure 1 presents the draft algorithm.

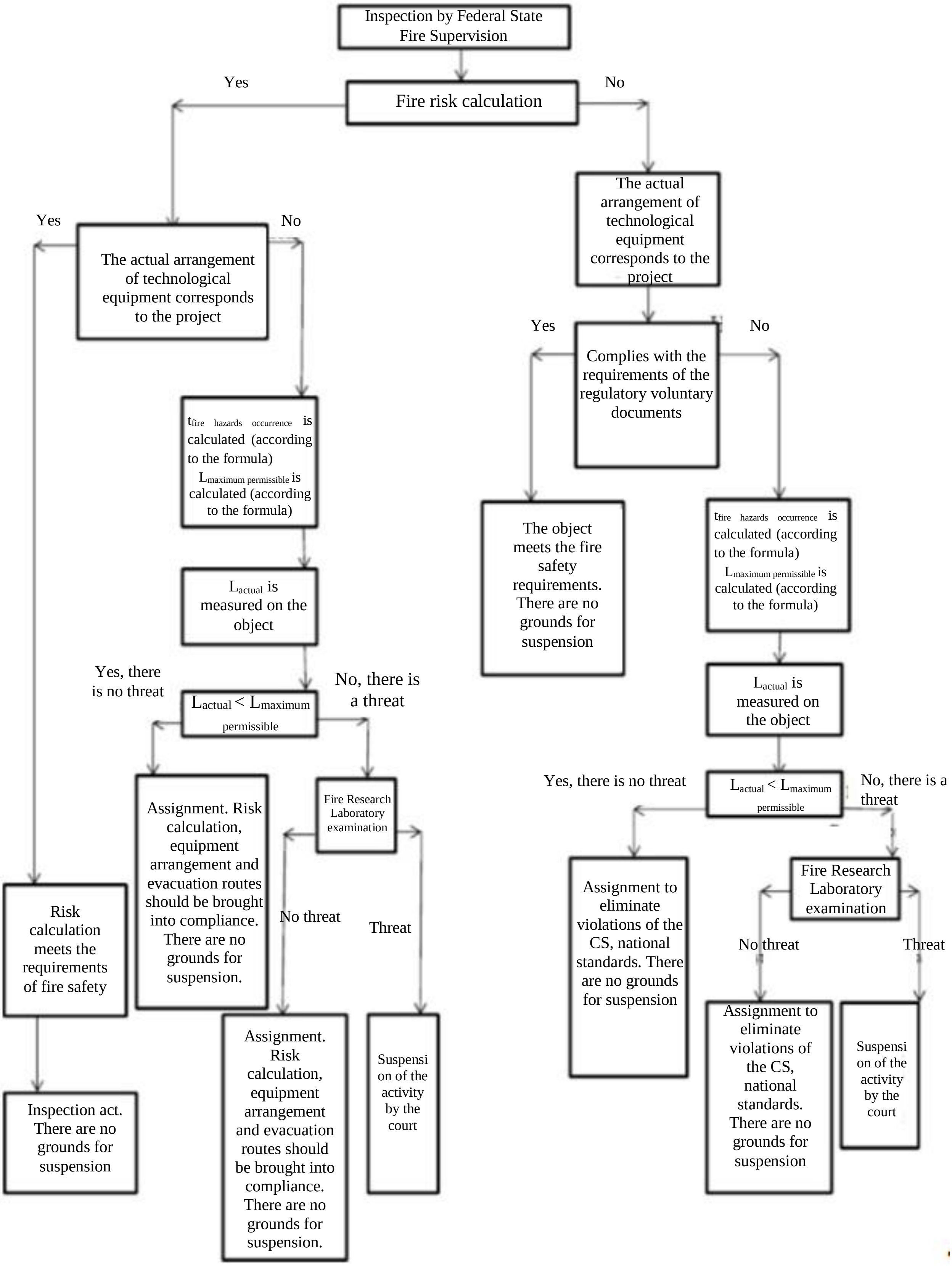
Inspection by Federal State Fire Supervision
Fire risk calculation
Yes
No
Yes
No
The actual arrangement of technological equipment corresponds to the project
The actual arrangement of technological equipment corresponds to the project
Yes
No
Complies with the requirements of the regulatory voluntary documents
t fire hazards occurrence is calculated (according to the formula) L maximum permissible is calculated (according to the formula)
L actual is measured on the object
Yes, there is no threat
No, there is a threat
L actual < L maximum permissible
The object meets the fire safety requirements. There are no grounds for suspension
t fire hazards occurrence is calculated (according to the formula) L maximum permissible is calculated (according to the formula)
L actual is measured on the object
Yes, there is no threat
L actual < L maximum permissible
No, there is a threat
Assignment. Risk calculation, equipment arrangement and evacuation routes should be brought into compliance. There are no grounds for suspension.
Fire Research Laboratory examination
No threat
Threat
Risk calculation meets the requirements of fire safety
Assignment to eliminate violations of the CS, national standards. There are no grounds for suspension
Fire Research Laboratory examination
No threat
Threat
Inspection act. There are no grounds for suspension
Assignment. Risk calculation, equipment arrangement and evacuation routes should be brought into compliance. There are no grounds for suspension.
Suspension of the activity by the court
Assignment to eliminate violations of the CS, national standards. There are no grounds for suspension
Suspension of the activity by the court

Fig. 1. The draft algorithm for supporting managerial decision-making on the compliance of commercial protection facilities with the fire safety requirements

Conclusion. Having analyzed the application of the developed algorithm for supporting managerial decision-making on the compliance of commercial protected facilities with the fire safety requirements, it can be concluded that this algorithm allows state fire supervision inspectors to assess the existence of a threat to human life and health during field inspections and decide on further actions depending on the presence or absence of this threat.

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On probabilistic-physical and entropy approaches to combustion processes and determination of fire hazard

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Introduction. The article provides an overview of the existing approaches to solving the problem of combustion of substances and materials, for their adequacy in determining their fire hazard of products and objects. The relevance of the work is due to the need to move from latent forms in determining the fire hazard of materials and products made from them (degrees of fire resistance, flammability groups, groups of the effectiveness of fire retardant coatings, etc.) to analytical forms describing the processes in the combustion theory.

Problem statement. The task of the research is to determine the relationship between the theory of combustion of substances and materials and to assess their fire hazard in natural and man-made systems.

Theoretical part. The system analysis of solutions to the combustion theory problems is performed. Its results became the basis of probabilistic-physical and entropy approaches, as well as proposals for changing standards designed to provide protection from fires.

Conclusions. The results of the study showed the need to revise empirical approaches in assessing the fire hazard of materials and products made from them, which includes using thermoanalytic and acoustic methods and means.

Keywords: combustion theory, fire hazard of substances and materials, probability of fire, entropy, baro-electro-thermo-acoustic analysis, vector-function of the life cycle of materials, fire safety of objects

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Introduction. According to the Center for Fire Statistics of the International Association of Fire and Rescue Services, up to 4.5 million fires are registered annually in the world, in which up to 60 thousand people die. The leader is the United States with an annual rate of 1.3 million fires. As for Russia, the maximum number of fires was recorded in 1996 — almost 300 thousand. [1][1].

According to the author of the presented work, such a situation has arisen and persists because fundamental science, having once solved the main combustion problems, has not bothered with applied tasks. Their unsatisfactory solutions, in addition to socio-economic losses, led to a steady increase in the number of fires and damage from them. The dynamics may not be so obvious if you focus only on government statistics that compare each year with the previous one [1][2]. A more accurate picture is given by the trend line. Figure 1 shows that it is ascending [3] [2]. It should be noted that the data from the end of the last century have been visualized and supplemented with information on electricity consumption. The correlation is obvious. Moreover, it proves the dependence of fires and related losses on the consumption of electricity by technosphere objects, i.e., on changes in the specific "power supply capacity" of the population and facilities.

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[2] Idem.

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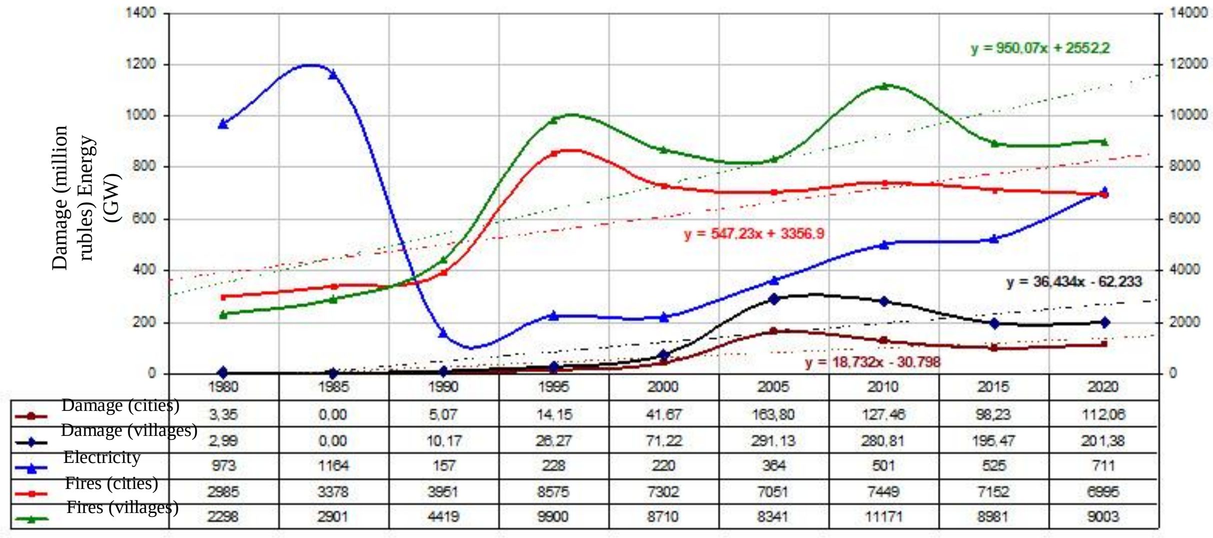

	1980	1985	1990	1995	2000	2005	2010	2015	2020
Damage (cities)	3,35	0,00	5,07	14,15	41,67	163,80	127,46	98,23	112,06
Damage (villages)	2,99	0,00	10,17	26,27	71,22	291,13	280,81	195,47	201,38
Electricity	973	1164	157	228	220	364	501	525	711
Fires (cities)	2985	3378	3951	8575	7302	7051	7449	7152	6995
Fires (villages)	2298	2901	4419	9900	8710	8341	11171	8981	9003

Fig. 1. Fires, their damage and energy consumption in the south of Russia (Rostov region, Krasnodar and Stavropol territories)

At the same time, the main causes of social losses from fires (Fig. 2) are combustion products (69.36 %) and high temperature (20.26 %) with concomitant factors (lack of oxygen — 3.93 % and exacerbation of diseases — 1.79%)[4] [2].

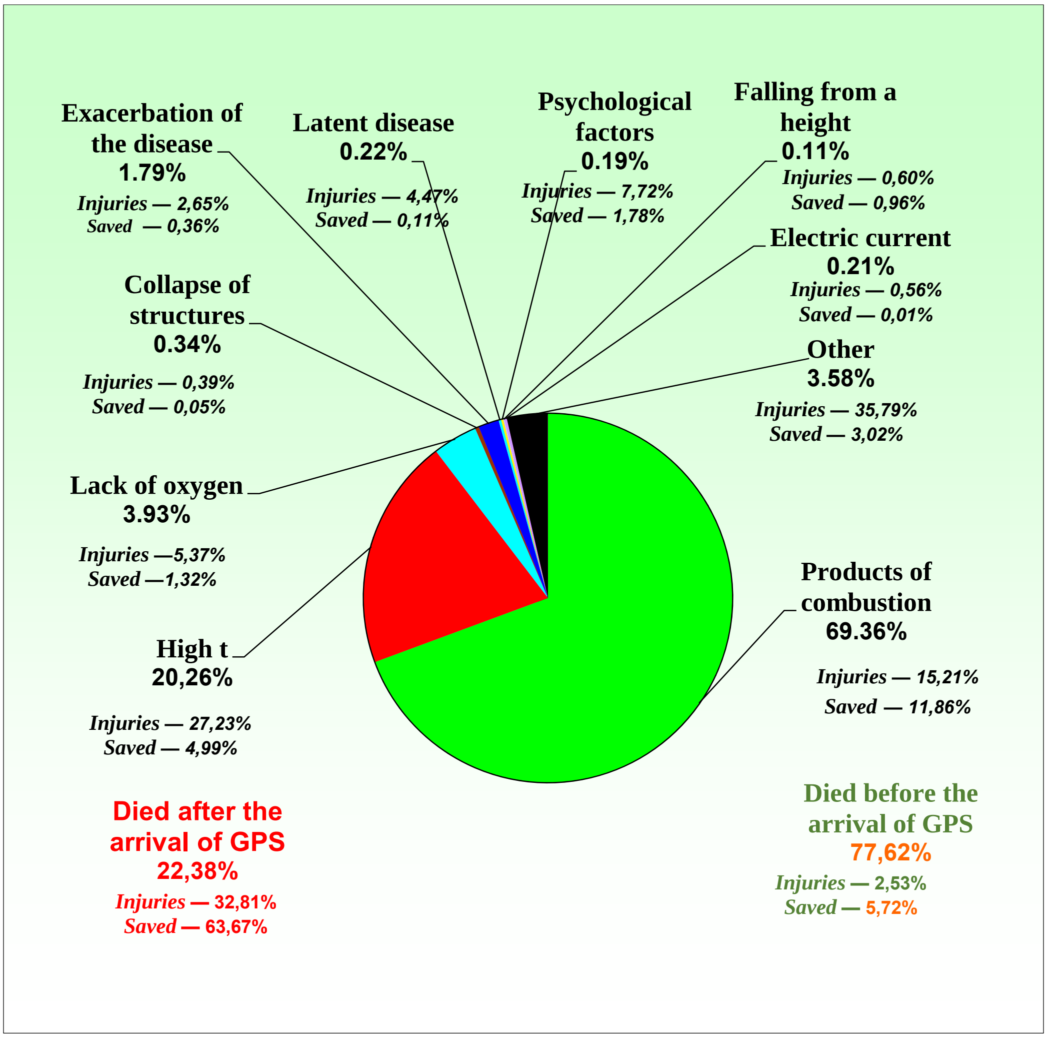

Fig. 2. Statistical data on the causes of deaths and injuries in fires in the south of Russia (Rostov region, Krasnodar and Stavropol territories)

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[4] Belozerov V. V. Op. cit.

According to the results of statistical analysis (Fig. 3), the main sources of fires are appliances and household items (including electric, gas appliances and stoves). They account for more than 70% of incidents. Approximately 26 % of cases involve careless handling of fire. 40 % of fires occur due to electrical and gas engineering reasons. They are associated with about 50% of direct material losses and damage to areas [5] [2].

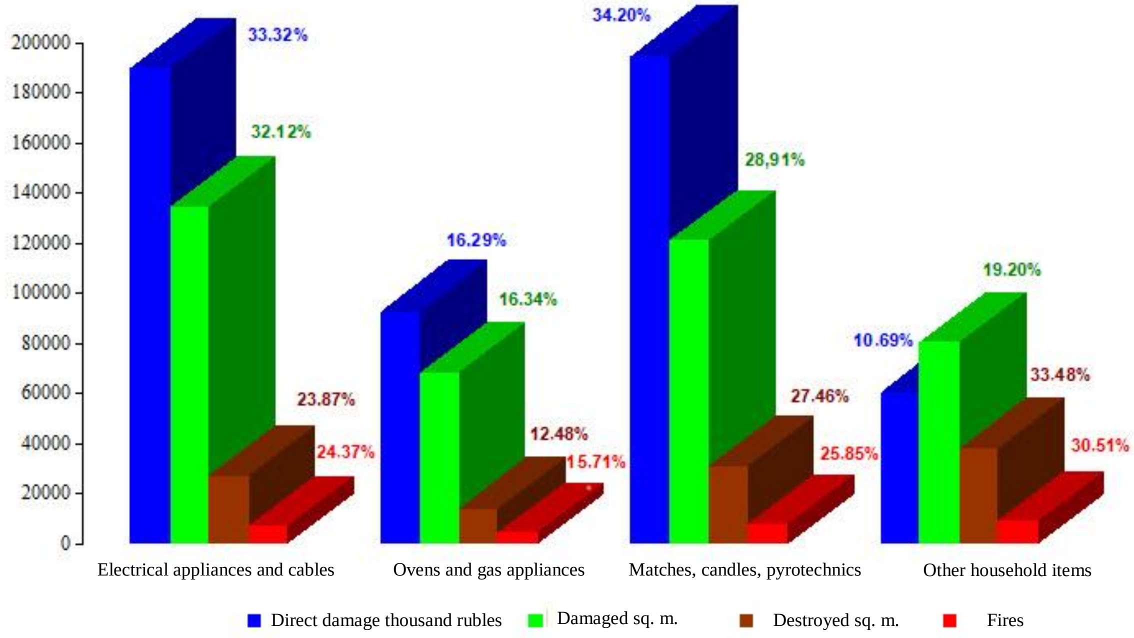

Fig. 3. Statistics on sources of fires and losses from them in the south of Russia (Rostov region, Krasnodar and Stavropol territories), shares in % for each group of sources

This situation has arisen because the firefighters themselves are engaged in working out fire safety issues. For example, specialists in this industry have created a "Technical Regulation on fire safety requirements", relevant standards and norms [2][6, 7].

Theoretical Part. The assessment of socio-economic losses from fires according to GOST 12.1.004 (the probability of fires is not higher than 10^{-6}, the safety of the population is not lower than 0.999999) gives the level of the "permissible" number of annual number of people dying in fires — no more than 146 people (for the 146 million population of Russia)[8].

Over the past 50 years, the annual losses in the country from fires have been more than 100 times higher than permissible. This proves the fallacy of methods and means for determining the fire hazard of man-made and natural systems, and hence the inadequacy of the existing methods and technical means of their fire protection[9] [2].

Moreover, during the development of the "Technical Regulations on fire safety requirements" and "Fire Safety Rules"[10, 11] the Ministry of Emergency Situations of Russia did not involve fundamental science in solving safety problems. Instead, the agency introduced new latent fire risk indicators. Two observations should be made regarding this approach. First. There is no satisfactory scientific theoretical justification for latent fire risk indicators yet, despite the attempts made [3]. Second. Even 10 years after the innovations of the Ministry of Emergency Situations, the situation has not practically changed, and this is confirmed by statistics[12] [2].

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[8] GOST 12.1.004 Fire safety. General requirements. Moscow: Publishing House of Standards, 1992. 77 p.

[9] Belozerov V. V. Op. cit.

[10] Technical regulations on fire safety requirements.

[11] Rules of fire protection regime in the Russian Federation.

[12] Fires and fire safety.

Another domestic standard — GOST 12.1.044 "Fire and explosion hazard of substances and materials" is a copy of international standards and has long required revision [13]. The document should be updated in terms of the use of thermoanalytic methods (thermogravimetry, differential scanning calorimetry, etc.) to determine the physico-chemical and thermodynamic characteristics of substances and materials. This will make it possible to abandon latent parameters (flammability groups, degrees of fire resistance, toxicity, etc.) [14] [4].

So, the reduction of losses from fires involves taking into account the thermodynamic characteristics of substances, materials and products made of them under operating conditions [5]. In addition, it is necessary to know the features of technical means, buildings, structures and other objects in general, surrounded by natural systems [4]. This approach will eliminate the possibility of an increase in entropy in each of the life support systems and subsystems, including social entropy caused by the human factor [4, 6].

From the above, it can be concluded that the main safety problems of man-made and natural systems are not being solved because international and national standards in this area are outdated and harmful. The methods and means used by them to determine the fire and explosion hazard and combustibility of substances and materials do not allow us to adequately assess their danger, and hence the danger of products made from them, equipment, transport and energy facilities and systems, buildings and structures[15] [2, 4].

So far, these main problems have not been solved. Therefore, the methods and means of fire protection are being developed and applied, which are not adequate to the real fire danger of objects and do not perform their functions, that is, they do not provide the safety parameters required by GOST 12.1.004[16].

It is appropriate to note that the head research organization of the Ministry of Emergency Situations of Russia (VNIIPO) has been conducting research on the fire hazard of substances and materials by thermal analysis methods for more than 10 years[17]. There are more than 3 thousand substances and materials in the data bank. In 2003, Belarus introduced into force some of its state standards of the characteristics of building materials determined by the methods and means of thermal analysis. In this regard, it can be concluded that there is a promising expansion of the use of thermoanalytical devices and physico-chemical parameters of materials instead of indirect methods and latent variables[18, 19].

From the point of view of fundamental and applied sciences, the most effective is the study of substances and materials at extreme pressures and temperatures, in vacuum, etc. So, for example, methods of thermal analysis: thermogravimetry, thermodilatometry, differential scanning calorimetry and others allow you to determine many important factors that can be divided into four groups. Firstly, these are the parameters of crystallization and melting points, sublimation and ignition, and phase transitions. Secondly, thermodynamic characteristics of materials: heat capacity, enthalpy, compression, expansion coefficients, etc. Thirdly, similarity criteria: thermal conductivity and Poisson's coefficients, Young's modules, Bio numbers, etc. Fourth, some "fire" indicators: heat of melting and combustion, oxygen index, etc. However, due to the difficulties of metrological certification of thermal analysis installations, the data obtained have significant errors and are mainly used for qualitative assessments [20, 21, 22].

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[13] GOST 12.1.044 Fire and explosion hazard of substances and materials. Nomenclature of indices and methods of their determination. Moscow: Publishing House of Standards, 1990. 143 p.

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For more than 40 years, fundamental and applied science has been using the acoustic emission (AE) method, based on the registration and analysis of acoustic radiation that occurs when the structure and physico-chemical properties of substances and materials change. The advantage of AE is its non-destructive nature. This is a necessary condition for the study of dissipative processes that characterize the degradation of parameters and "aging" of substances and materials, which makes it possible to predict changes in their structure and properties under operating conditions [7, 8].

As studies have shown [23] [8], AE makes it possible to accurately register some "fire" parameters: the stages of melting, pyrolysis, ignition and combustion. For this purpose, this method should be used synchronously with thermogravimetry and thermodilatometry of the sample. However, bearing in mind the accuracy and reliability of the results, it is worth noting that AE devices and installations have the same metrological difficulties as thermal analysis devices [7, 8].

Therefore, when studying substances and materials in real operating conditions, it is advisable to use a probabilistic-physical approach, as well as a thermodynamic interpretation of degradation processes. This is the most promising direction, including from the point of view of objectification of fire hazard parameters [4–6][24].

To date, several approaches have been adopted in fundamental and applied science to determine the conditions of ignition (self-ignition and ignition) of substances and materials.

The first one was developed by Nobel laureate academician N. N. Semenov. This is the founder of the theory of combustion, who proposed to consider the sources of heat release Arrhenius, and heat removal — Newtonian, provided the same temperature throughout the reacting mas [9]:

$$\frac{E_a}{RT_s^2}\cdot\frac{QV}{\alpha F}\cdot k\cdot\exp\left(-\frac{E_a}{RT_s}\right)\geq\frac{1}{e} \tag{1}$$

where E_a — the activation energy, $J{\cdot}mole^{-1}$; R — gas constant, 8.3 $J{\cdot}mole^{-1}\ K^{-1}$; Q — heat effect of reaction, $J{\cdot}mole^{-1}$; α — heat transfer coefficient, $W{\cdot}m^{-2}{\cdot}K^{-1}$; F — surface area, m^2; V — volume of material, m^3; k — pre-exponent; e — base of natural logarithms; T — temperature of auto-ignition of a substance (gas mixture), K.

An alternative to the Semenov criterion (1/e) was the approach developed at the Research Institute for Fire Protection. The self-ignition temperature T was associated by a power function with the surface area of the material F and its volume V [10]:

$$T_{ign}=A_p\cdot\left(\frac{F}{V}\right)^{n_p} \tag{2}$$

Here A_p — the empirical coefficient; $n_p=\frac{E_a/RT_A}{(E_a/RT_A+1)}$ — the exponent of the power function, where T_A — the ambient temperature. The other designations are the same.

The disadvantage of both methods: when determining the conditions of spontaneous ignition of substances and materials, the heterogeneity of heating of the reacting mass was not taken into account. The remaining shortcomings and errors relate to the accuracy and reliability of parameter determination. They are listed below[25, 26] [10].

— The Semenov criterion (1/e) should not take a value that is the reverse of the base of natural logarithms. It should be calculated, for example, as the ratio of the derivatives of the heat release rates.

— The temperature in the VNIIPO formula should be expressed in Kelvin, so as not to lead to false results when the temperature tends to zero on the Celsius scale.

D. A. Frank-Kamenetsky overcame these shortcomings by analytically solving the stationary problem of thermal self-ignition [11]:

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[23] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[24] Idem.
[25] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[26] Belozerov V. V. On the expediency of revising the basic "fire" standards.

$$\frac{E}{RT_O^2}\cdot\frac{Q\ell^2}{\lambda}\cdot k\cdot\exp\left(-\frac{E}{RT_O}\right)\geq\delta_{\text{КР}} \qquad (3)$$

where, $\delta_{\text{КР}}$ — th dimensionless Frank-Kamenetsky criterion; λ — the material thermal conductivity coefficient, $W\cdot m^{1}\cdot K^{-1}$; *r* — the determining size of the material (combustible medium), m. The other variable designations were given above.

The criterion was calculated by D. A. Frank-Kamenetsky under the condition of unlimited heat transfer for three basic geometric shapes: a cylinder (2.00), a ball (3.32) and a plane (0.88). Later, with the guidance of A. G. Merzhanov, such dependence was found for natural heat exchange [12]:

$$\delta_* = \frac{8a_*^2}{\left(a_*^2+1\right)^2}\cdot\exp\left\{\frac{-4a_*^2}{\left(a_*^2+1\right)Bi}\right\}\quad a_* = \sqrt{\sqrt{\frac{4}{Bi^2}+1}-\frac{2}{Bi}} \qquad (4)$$

where $Bi = \alpha\cdot\ell/\lambda$ — the number of Bio (including radiation: $Bi_p = \sigma\cdot T^3\cdot\ell/\lambda$).

However, due to the approximation of the Arrhenius exponent by the Frank-Kamenetsky series, his method has the following disadvantages [27], [28] [10]:

— mathematical complexity and practical inconvenience of using dimensionless parameters;

— incorrect assumption about the nonlinearity of the heat sink from the sample with internal heat removal, and as a result — inconsistency with the critical condition of thermal self-ignition according to the Semenov diagram.

These shortcomings were eliminated by the method of Y. S. Kiselev. He introduced into the Semenov equation a criterion named after him — the ratio of the derivatives of the heat release rates, as well as the pre-exponent of the volumetric reaction rate and the criterion of uneven heating [10]:

$$\frac{E}{RT^2}\cdot\frac{QZ}{\rho\cdot c_P}\cdot exp\left(-\frac{E}{RT}\right)\geq\frac{\psi\cdot Se\cdot\alpha\cdot F}{\rho\cdot c_P\cdot V}, \qquad (5)$$

where *E* — activation energy, $J\cdot mole^{-1}$; *R* — gas constant, 8,3 $J\cdot mole^{-1}\,K^{-1}$; *Q* — thermal effect of the reaction, $J\cdot mole^{-1}$; c_P — specific heat capacity $J\cdot kg^{-1}\cdot K^{-1}$; ρ — density of the material, $kg\cdot m^{-3}$; α — heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$; *F* — surface area, m^2; *V* — volume of the material, m^3; $Q\cdot Z/\rho\cdot C_P$ — pre–exponent of the volumetric reaction rate, $mole\cdot m^{-3}\cdot c^{-1}$; *T* — self-ignition temperature of the substance (combustible mixture) and the environment, K; $T_0 = T — RT^2/E$ (Todes ratio) — ambient temperature, K; $\psi = \dfrac{n\cdot\lambda}{\alpha\cdot\ell+n\cdot\lambda}$ — the Kiselev criterion, where the relative gradient *n* for a plane, an infinite cylinder, a sphere, a cube and a finite cylinder is 2.38; 2.71; 3.01; 2.29 и 2.50 respectively.

The approach developed by Ya. S. Kiselev, which is based on the analysis of heat flows, also has a number of disadvantages. In particular, the relative gradient introduced in it does not have a calculation function yet. At the same time, its advantage is obvious, since the formulas of Semenov, Frank-Kamenetsky and Taubkin (VNIIPO) are partial solutions to his equation (5).

The second approach describing ignition (in particular, ignition by a flat wall) was developed by academician Ya. B. Zeldovich. He determined the critical density of the heat flux and derived the following equation for the dimensional value of the heat flux [13]:

$$q=\sqrt{2\lambda\frac{RT_S^2}{E}\cdot Q\cdot k\cdot exp\left(-\frac{E}{RT_S}\right)}. \qquad (6)$$

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[27] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[28] Belozerov V. V. On the expediency of revising the basic "fire" standards.

Here q — critical heat flux density, W/m^2; T_S — wall temperature, ºK; λ — thermal conductivity coefficient of the gas phase. The rest designations of the variables are given above.

Another criterion for ignition of the condensed substances heated by a thermal pulse was proposed by corresponding member of the USSR Academy of Sciences A. A. Kovalsky and academician A. G. Merzhanov [14, 15]:

$$\frac{1}{\alpha} ln\, F(\gamma) \cdot q \cdot K_0\, exp\left(-\frac{E}{RT_m}\right) = \frac{\lambda \cdot \alpha \cdot \Delta T_m}{F(\gamma)} \text{ here } F(\gamma) = \frac{1 + RT_m/E}{1 - RT_m \cdot T_0/\Delta T_m} \tag{7}$$

Here T_m — ignition temperature, T_0 — sample temperature. The rest designations of the variables are given above.

I. S. Lyubchenko and corresponding member of the Academy of Sciences of the Republic of Tatarstan G. N. Marchenko proposed an asymptotic ignition criterion for reacting condensed substances:

$$q = 1{,}39\sqrt{\sqrt{\left(\frac{E(T_S - T_O)}{RT^2}\right)} \cdot \frac{\lambda \cdot \rho \cdot Q \cdot K \cdot RT^2}{E} \exp\left(\frac{E_a}{RT}\right)} \tag{8}$$

Here T_S — wall temperature, T_o — sample temperature. The rest designations of the variables are given above.

Taking into account the stationary heat removal from the reaction zone, the critical equation of the heat flux density (including for a non-degenerate ignition mode with asymmetric heating) clarifies the Zeldovich formula [13, 17]:

$$q^2 = 2\lambda \cdot \rho \cdot \frac{RT_S^2}{E} \cdot Q \cdot K \cdot exp\left(-\frac{E}{RT_S}\right) \tag{9}$$

All these approaches describe well enough the particular cases of fires. However, they, firstly, do not allow predicting the occurrence of fires in real operating conditions of industrial and residential facilities. Secondly, finding the activation energies included in the above equations is a difficult experimental task for any material. The problem is caused by the fact that instrument methods and means do not allow you to create isothermal conditions and to fix the parameters of the stages of melting, smoldering and ignition of substances and materials with the necessary accuracy and reliability[29, 30].

The third approach, integrating all the previous ones, was developed by Rostov scientists together with the staff of the Academy of State Fire Service of the Ministry of Emergency Situations of Russia[31,32,33,34] [4, 7]. It made it possible to overcome these methodological and instrumental difficulties, and most importantly — to link the parameters of the ignition and combustion processes[35] with the probability of a fire[36].

The proposed method of baroelectrothermoacustometry (BETA) and BETA-analyzer, that implements it, allow you to define multivariable vector-function of the life cycle (VGLC) of a sample of any material —$F\ [P, T, m_i, \ell_i, \rho_i, \lambda_i, a_i, Cp_i, Cv_i, \beta_i, \gamma_i, \zeta_i, h_i, \chi_i, \psi_i, H_i, Fo_i, B_i, E_i, K_i, G_i, v_i, \rho_i g \cdot \ell_i/E_i, \sigma_i, |Z_i|, C_i(R_i), tg\sigma_i, \varepsilon_i, \mu_i, \mu_i \cdot \ell_i 2/\sigma_i t, L_i/R_i t, \varepsilon_i \cdot \sigma_i/t, C_i/\sigma_i t, Na_i, U_i, G_i, \eta_i)$. The changes in the VGLC are made up into a function of entropy production without data loss on reversible and irreversible processes up to destruction or ignition and combustion of the sample[37, 38, 39] [18] In contrast to the previous solutions, it is proposed to reduce the Semyonov and Zeldovich inequalities with the Franz-Kamenetsky and Lyubchenko—Marchenko equations into a system of equations (10) in order to use a BETA analyzer

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[29] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[30] Molchadskiy O. I., Smirnov N. V., Duderov N. G. Op. cit.

[31] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[32] Belozerov V. V., Belozerov V. V., Bosyy S. I. et al. Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation. Patent 2343467 Russian Federation, IPC G01N 27/00/No. 2006125486/28, 2009, 26 p.

[33] Belozerov V. V. On the expediency of revising the basic «fire» standards.

[34] Belozerov V. V., Buylo S. I., Prus Yu. V. Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation. Patent 2324923 Russian Federation, RU 2006 126 287 A/No. 2006126287/28; 2008, 1 p.

[35] GOST 12.1.044 Fire and explosion hazard of substances and materials. Nomenclature of indices and methods of their determination.

[36] GOST 12.1.004 Fire safety. General requirements. Moscow: Publishing House of Standards.

[37] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[38] Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation.

[39] Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation.

to find a solution at the ignition point of the sample recorded by acoustic emission signals, taking into account the design (Fig. 4) of the thermoelectrodylatometer crucible (TED) and the assumptions that are given after explication[40, 41]:

$$\begin{cases} Se = \dfrac{Q \cdot V}{F \cdot \alpha} \cdot \dfrac{E_a\, K_{Se}}{RT_{\Pi O}^2} \cdot \exp\left(-\dfrac{E_a}{RT_{\Pi O}}\right) \\ q = \sqrt{\dfrac{2\lambda_B RT_{\Pi O}^2 \cdot Q \cdot K_{Ze}}{E_a} \cdot \exp\left(-\dfrac{E_a}{RT_{\Pi O}}\right)} \\ F_\kappa = \dfrac{Q \cdot r^2}{\lambda_O} \cdot \dfrac{E_a}{RT_O^2} \cdot K_{Fk} \cdot \exp\left(-\dfrac{E_a}{RT_O}\right) \\ q^2 = \dfrac{2\lambda_O \rho \cdot Q \cdot K_{Lu} \cdot RT_{\Pi O}^2}{E_a} \cdot \exp\left(-\dfrac{E_a}{RT_{\Pi O}}\right) \end{cases} \qquad (10)$$

Here q — critical heat flux density; λ_B — thermal conductivity coefficient of the gas phase (air); λ_O — thermal conductivity coefficient of the sample; ρ — sample density; R — gas constant; E_a — activation energy of the processes in the sample; Q — thermal effect of the reaction; Ki — pre-exponents; Se — the Semenov criterion ($Se = 0.368$); V — current volume of the sample; F — current surface area of the sample; α — current heat transfer coefficient of the sample; $T_{\Pi O}$ — surface temperature of the sample; $F\kappa$ — the Frank—Kamenetsky criterion ($F\kappa = 2.00$); r — characteristic size of the sample; $To = T_{\Pi O} - (T_{\Pi O} - T_H)/2$ — average temperature of the sample.

Here are the assumptions mentioned above.

— The test samples are made in the form of a cylinder (viscous and liquid are poured into a thin molybdenum "glass") and placed in a thermoelectrodylatometer (TED). It is equipped with a movable "float" and two fixed temperature sensors (Fig. 4). The temperature of the bottom Tb and the temperature of the cover Tc are equal to the temperature of the furnace. The surface temperature of the sample is Ts. The average volume value of the sample temperature: $TV = (T_b - Ts)/2$.

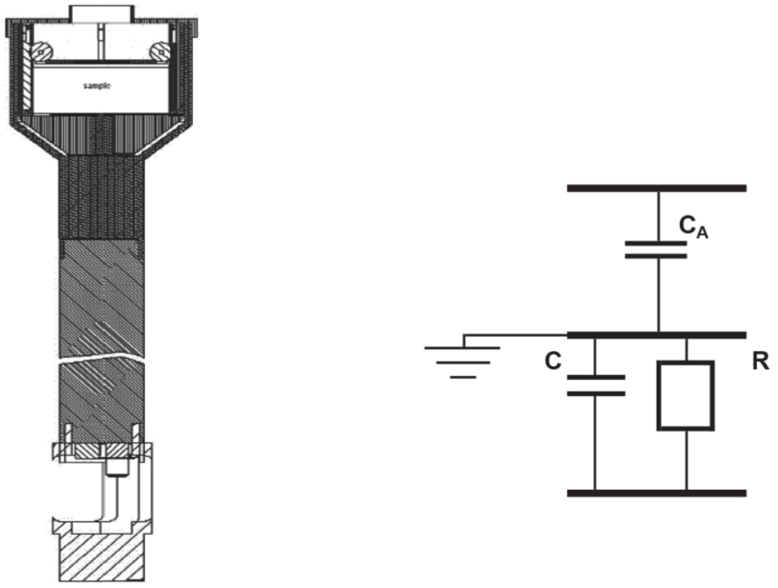

Fig. 4. Thermoelectrodylatometer for solid, liquid and viscous materials and its equivalent circuit

— The stages of thermal destruction and the moment of ignition are recorded using two AE sensors installed at the outer ends of molybdenum thermoacoustic waveguide rods. Two of their half-cones are inserted into the bottom of the TED and are in contact with the test sample.

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[40] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[41] Belozerov V. V. On the expediency of revising the basic "fire" standards.

— TED (fig. 4) is made of zirconium ceramics. Its thermal conductivity coefficient is about 1.0 W/(m•K). Molybdenum plates (bottom, cover and movable "float") have thermal conductivity coefficient of about 130 W/(m•K) and allow you to create a unidirectional adjustable heat flow into the sample with a determined density q(W/m^2) and lateral heat dispersion of less than 1 %.

These assumptions, according to the author, are correct if we take into account that the Semenov equation uses the heat transfer coefficient from the sample surface [9], the Frank-Kamenetsky and Lyubchenko—Marchenko equations use the thermal conductivity coefficient of the sample [11, 12], and the Zeldovich equation uses the thermal conductivity coefficient of the gas phase from the "wall" to the sample (in this measurement scheme — to the float). That is, the temperature of the ignition wall is the temperature of the float on the surface of the sample [42] [13].

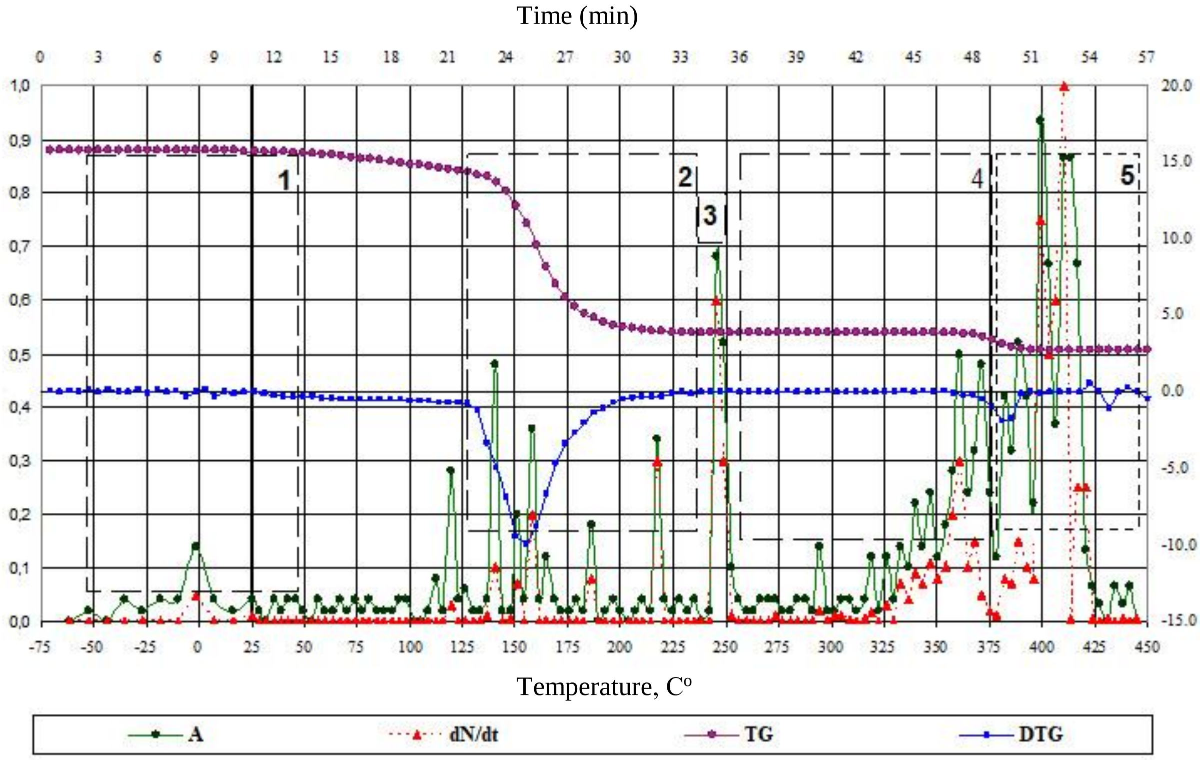

Fig. 5. Thermograviacustometry of the polymer: 1 —zone of thermal destruction of the sample during operation (from –50 °C to +50 °C); 2 —pyrolysis zone of the sample; 3 — ignition point of the sample; 4 —combustion of the sample; 5 — zone of coke residue formation. The normalized amplitude and the intensity of acoustic emission are shown on the left scale, and the change in the mass of the sample in grams is shown on the right scale

During thermal cycling (heating — cooling) of a sample, it is possible to register and calculate the thermokinetic parameters (E_{Di} and QK_{Di}) of the stages of its thermal destruction: crystallization, occurrence of flow channels, melting or evaporation, pyrolysis, ignition, combustion and coke residue formation (Fig. 5). All this is reliably recorded by AE signals. According to these stages, it is possible to construct vector functions of the life cycle (VFLC) of the sample, including the aging processes during operation[43, 44, 45, 46] [18].

High accuracy of the VFLC parameters is ensured by the dynamic metrology of the measuring channels of the beta analyzer using thermodynamic acoustic emission standards built into TED. These standards, which are "droplets" of mercury and water, are soldered into the thermoacoustic waveguide rods, forming the "TED bottom". Due to the anhysteretical characteristics of phase transitions of the first kind, they allow calibration of measuring channels during tests. The method of such standardization is protected by a patent of the Russian Federation[47].

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[42] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[43] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[44] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[45] Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation.

[46] Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation.

We will take into account the initial calibration of the sample in TED before testing under normal conditions: the exact determination of mass — m, linear size — ℓ, density calculation — ρ, volume — V, sample radius — r and coefficient $\psi = r/\ell$). In this case, to solve system (10), the following measured TED parameters are substituted into its equations and the following formulas are used:

— the current radius of the sample (characteristic dimension) r → (m) $r = \psi\cdot\ell(T)$;

— the current thermal conductivity coefficient of the sample → (W/m·°K) $\lambda_O(T)$;

— the current heat transfer coefficient of the sample → (W/m^{2}·°K) $\alpha = Bi\cdot\lambda_O(T)/\ell(T)$, where the number of Bio is given by e $Bi = \sigma T^3\ell(T)/\lambda_O(T)$;

— the current volume of the sample → (m^3) $V(T) = \pi\cdot\psi^2\cdot\ell^3(T)$;

— the current surface area of the sample (cylinder) → (m^2) $F(T) = 2\pi\cdot\psi^2\cdot\ell^2(T) + 2\pi\cdot\psi\cdot\ell^2(T) = 2\pi\cdot\psi\cdot\ell^2(T)\cdot(\psi+1)$.

In the last case, the initial calibration of the sample in TED before testing under normal conditions is taken into account (accurate determination of mass m, linear size ℓ, as well as density calculation ρ, volume V, sample radius r and coefficient $\psi = r/\ell$).

System (10) is solved by substitution in several stages. This is how it differs from previous methods [48, 49] taking into account the results of the analysis of the dimension of variables in the equations.

First step. By dividing the second equation by the third ($Se/F\kappa$) with substitution of the values of all variables measured at the ignition point, the ignition activation energy E_a is determined:

$$\frac{Se}{F_K}=\frac{\lambda_O RT_O^2\cdot Q\cdot V\cdot E_a\cdot K\exp\left(-\dfrac{E_a}{RT_{ПО}}\right)}{r^2 Q\cdot E_a K\exp\left(-\dfrac{E_a}{RT_O}\right)RT_{\text{ПО}}^2\cdot F\cdot\alpha\cdot}=\frac{T_O^2\exp\left(\dfrac{E_a}{RT_O}\right)}{2\psi\ (\psi+1)\cdot T_{\text{ПО}}^2\cdot \mathrm{Bi}\cdot\exp\left(\dfrac{E_a}{RT_{ПО}}\right).}=\frac{T_O^2}{2\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\cdot\mathrm{Bi}}\exp\left(\frac{E_a}{RT_O}-\frac{E_a}{RT_{ПО}}\right)\cdot$$

Let us substitute the criteria of Semenov and Frank-Kamenetsky (for the cylinder-sample) and find the logarithm:

$$E_a\left(\frac{T_{ID}-T_O}{RT_OT_{ID}}\right)=\ln\frac{F_K\cdot T_O^2}{2Se\cdot\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\mathrm{Bi}}\to E_a=\frac{RT_OT_{ID}}{T_{ID}-T_O}\cdot\ln\frac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\mathrm{Bi}}\ . \tag{11}$$

Second step. Let us substitute (11) into the equations of system (10) and determine thermokinetic complexes QKi:

$$\begin{gathered}Se=\frac{Q\cdot\pi\cdot\psi^2\cdot\ell^3\cdot\dfrac{RT_OT_{ID}}{T_{ID}-T_O}\cdot\ln\dfrac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\mathrm{Bi}}\cdot K_{Se}}{2\pi\cdot\psi\cdot\ell^2(\psi+1)\cdot\dfrac{Bi\cdot\lambda_O}{\ell}\cdot RT_{ПО}^2}\cdot\exp\left(-\frac{\dfrac{RT_OT_{ID}}{T_{ID}-T_O}\cdot\ln\dfrac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\mathrm{Bi}}}{RT_{ID}}\right)\to\\ QK_{Se}=\frac{2(\psi+1)\cdot Bi\cdot\lambda_O\cdot T_{ПО}(T_{ID}-T_O)}{e\cdot\psi\cdot\ell^2\cdot T_O\cdot\ln\dfrac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\mathrm{Bi}}}\cdot\exp\left(\frac{T_O}{T_{ID}-T_O}\cdot\ln\frac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\mathrm{Bi}}\right)\end{gathered}\tag{12}$$

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[47] Belozerov V. V., Bosyy S. I., Buylo S. I. The method of thermodynamic acoustic emission standardizing and the system implementing it. Patent 2399910 Russian Federation,: G01N 25/02, G01N 29/14/. No. 2399910, 2010.
[48] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.
[49] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

$$q^2 = \frac{2\lambda_B RT_{\text{ПО}}^2 \cdot Q \cdot K_{Ze}}{\frac{RT_O T_{\text{ПД}}}{T_{\text{ПД}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}} \cdot \exp\left(- \frac{\frac{RT_O T_{\text{ПД}}}{T_{\text{ПД}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}}{RT_{\text{ПО}}} \right) \to$$

$$QK_{Ze} = \frac{q^2 T_O \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot Bi}}{2\lambda_B T_{\text{ПО}}(T_{\text{ПО}} - T_O)} \exp\left(\frac{T_O}{(T_{\text{ПО}} - T_O)} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot Bi} \right) \qquad (13)$$

$$F_{к} = \frac{Q \cdot K_{Fk} \cdot \psi^2 \ell^2 \frac{RT_O T_{\text{ПД}}}{T_{\text{ПД}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}}{\lambda_O RT_O^2} \cdot \exp\left(- \frac{\frac{RT_O T_{\text{ПД}}}{T_{\text{ПД}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}}{RT_O} \right) \to$$

$$QK_{Fk} = \frac{2\lambda_O T_O (T_{\text{ПО}} - T_O)}{\psi^2 \ell^2 T_{\text{ПД}} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}} \exp\left(\frac{T_{\text{ПД}}}{T_{\text{ПД}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}} \right) \qquad (14)$$

$$q^2 = \frac{2\lambda_O \rho \cdot RT_{\text{ПО}}^2 \cdot Q \cdot K_{Le}}{\frac{RT_O T_{\text{ПД}}}{T_{\text{ПД}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}} \cdot \exp\left(- \frac{\frac{RT_O T_{\text{ПД}}}{T_{\text{ПД}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}}{RT_{\text{ПО}}} \right) \to$$

$$QK_{Le} = \frac{q^2 T_O \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot Bi}}{2\lambda_O \rho \cdot T_{\text{ПО}}(T_{\text{ПО}} - T_O)} \exp\left(\frac{T_O}{(T_{\text{ПО}} - T_O)} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot Bi} \right) \qquad (15)$$

Formulas (11–15) allow recording and calculating thermokinetic parameters (E_{Di} и QK_{D}i) of all stages of thermal degradation of samples.

Researches [50], [51], [52], [53], [54] [18] show that prior to mass loss of the sample as a result of the processes of thermal destruction (i.e., before the registration of m_0 changes) the thermal energy received by the sample goes to:

— the change its structure and temperature, i.e. heating and phase transitions (flow thresholds, melting, etc.), which is registered by the acoustic emission signals (Fig. 5);

— the interaction (heat exchange and radiation) with the environment.

Therefore, it can be argued that the activation energy at the ignition point E_a is the bond energy E_b, i.e. the following equalities can be used [19]:

$$E_b = ST = \Delta mc^2, \qquad (16)$$

$$E = E_o + E_b + A = m_o c^2 + \Delta mc^2 + A. \qquad (17)$$

Here E_b — energy spent on the formation of new internal connections, including changes in the mass and volume of the sample; S — energy spent on the formation of new internal connections, including changes in the mass and volume of the sample; T — absolute temperature characterizing in this case the speed of processes in the object;

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[50] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[51] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[52] Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation.

[53] Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation.

[54] The method of thermodynamic acoustic emission standardizing and the system implementing it.

Δm — change in the mass of the object; c — the speed of light; E — the total energy of the object under consideration; E_{o} — internal energy; A — energy spent on superfacial work (free energy); m_o — mass of the object.

In this case, activation energy equation (11) can be written as follows [55]:

$$E_a = ST_O = \frac{RT_O T_{ПД}}{T_{ПД} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \text{Bi}} \tag{18}$$

From here we get a formula for calculating the entropy of dissipation (activation):

$$S = \frac{RT_{ПД}}{T_{ПД} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \text{Bi}} \tag{19}$$

Let us substitute expressions (18 and 19) in (10) and write a new system (20). It will make it possible to obtain thermokinetic complexes (QK_{Di}) of samples (21)–(24) at all stages of the life cycle, for subsequent calculation through the difference between the stages — entropy production functions (ΔSi) which characterize the degradation of properties:

$$\begin{cases} Se = \dfrac{Q \cdot V \cdot S \cdot K_{Se}}{F \cdot \alpha \cdot RT_{ПО}} \cdot exp\left(-\dfrac{S}{R}\right); \\ q = \sqrt{\dfrac{2\lambda_B RT_{ПО} \cdot Q \cdot K_{Ze}}{S} \cdot exp\left(-\dfrac{S}{R}\right)}; \\ F_\kappa = \dfrac{Q \cdot \psi^2 \ell^2 S \cdot K_{Fk}}{\lambda_O RT_O} \cdot exp\left(-\dfrac{S}{R}\right); \\ q^2 = \dfrac{2\lambda_O \rho \cdot Q \cdot K_{Lu} \cdot RT_{ПО}}{S} \cdot exp\left(-\dfrac{S}{R}\right). \end{cases} \tag{20}$$

$$QK_{Se} = \frac{2(\psi+1)Bi \cdot \lambda_O \cdot T_{ПО}(T_{ПД} - T_O)}{e \cdot \psi \cdot \ell^2 \cdot \ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \text{Bi}}} \cdot \exp\left(\frac{T_O}{T_{ПД} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \text{Bi}}\right) \tag{21}$$

$$QK_{Ze} = \frac{q^2 T_O \cdot \ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{ПО}^2 \cdot Bi}}{2\lambda_B T_{ПО}(T_{ПО} - T_O)} \exp\left(\frac{T_O}{T_{ПД} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \text{Bi}}\right) \tag{22}$$

$$QK_{Fk} = \frac{2\lambda_O T_O (T_{ПО} - T_O)}{\psi^2 \ell^2 T_{ПД} \cdot \ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \text{Bi}}} \exp\left(\frac{T_{ПД}}{T_{ПД} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \text{Bi}}\right) \tag{23}$$

$$QK_{Le} = \frac{q^2 \cdot ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{ПО}^2 \cdot Bi}}{2\lambda_O \rho \cdot T_{ПО}(T_{ПО} - T_O)} exp\left(\frac{T_O}{(T_{ПО} - T_O)} \cdot ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{ПО}^2 \cdot Bi}\right) \tag{24}$$

This demonstrates the possibility of implementing an analytical, quantitative approach to the fire hazard of materials. There is an obvious need to replace the methods and means of their determination. Instead of GOST 12.1.044, a new edition should be introduced, which uses methods and means of baroelectrothermoacoustic beta analysis, which are developed in Russia [56, 57, 58, 59, 60] [18].

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[55] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[56] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[57] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[58] Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation.

In this case, from the point of view of further interaction of these basic standards, of course, it is necessary to correct GOST 12.1.004. It is necessary to eliminate errors in the dimension of events and in the method of "introducing malfunctions in electrical appliances". Let us take a closer look at the weaknesses of this document [61, 62, 63].

First, the probability of any event is a dimensionless quantity. However, GOST 12.1.004 (as well as the "Technical Regulations on fire safety requirements") fixes the permissible level of probability of fire in equipment or object (in the "Technical Regulations" we are talking about fire risk) 10^{-6} per year. From the point of view of reliability and probability theories, this is the intensity of the event λ with a generally accepted dimension of 1/hour. In other words, $1.14 \cdot 10 - 10$ hour^{-1}, because one millionth has to be divided into 8760 hours, of which the year consists [64].

Secondly, for fire hazard tests of radio-electronic and electrical equipment and devices, the methodology for introducing malfunctions fixed in these documents is used. It must be excluded. The fact is that this erroneous approach requires the application of a complex section of reliability theory — the theory of dependent failures. Artificial "shutdown", i.e., the closure or breakage of any RE of the product activates the emergency mode not in it, but in schematically connected other electrical and radio elements. This causes the incorrectness of further calculation of the probability of fire, because the conditions of applicability of probability distribution formulas requiring independence of events are violated[65, 66, 67].

The first error can be eliminated by introducing the concept of "fire-safe resource" (material, product, etc.) and the requirements of its commensurability with the technical resource, i.e. with the service life of the material, equipment, premises and object. The correct wording would be: "The probability of a fire in the equipment or object should not exceed 10^{-6} during its service life." We will show how in this case (for example, taking into account the exponential distribution generally accepted in GOST R 27.403) the permissible intensity λ_A is determined when creating (designing and manufacturing) a product (object). Knowing the time of consumption of the "fire-safe resource" during operation (t_{FR}), we log the distribution function:

$$10^{-6} = 1 - \exp(-\lambda_A t_{FR}) \to \quad \lambda_A = \left(\frac{\ln(1) - \ln(1 - 10^{-6})}{t_{FR}} \right) \tag{25}$$

It is appropriate to recall that Federal Law 123-FZ "Technical Regulations on fire safety requirements"[68] introduced the concept of "fire risk". According to the author, this, firstly, is not justified by anything. Secondly, it confuses and contradicts the concept of the risk function — $h(x)$. In the probability theory, it is defined as the ratio of the probability density function — $f(x)$ to the survival function — $S(x)$ at point x. With an exponential distribution, its value is equal to the intensity of the event — λ_A, i.e. in this case, the intensity of the fire [69, 70, 71]:

$$h(t_{\text{П}}) = \frac{f(t)}{S(t)} = \frac{\lambda_{\text{П}} \exp(-\lambda_{\text{П}} \cdot t_{\text{ПБР}})}{\exp(-\lambda_{\text{П}} \cdot t_{\text{ПБР}})} = \lambda_{\text{П}}. \tag{26}$$

It is advisable to eliminate the second error using a probabilistic-physical model obtained in the form of lognormal distribution functions. What is meant here is the additional heat of each element in a fire hazard failure:

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[60] The method of thermodynamic acoustic emission standardizing and the system implementing it.
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[67] GOST R 27.403-2009 Dependability in technics. Compliance test plans for reliability.
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[70] Belozerov V. V. On the expediency of revising the basic "fire" standards.
[71] GOST R 27.403-2009 Dependability in technics. Compliance test plans for reliability.

$$F_e(Q) = 1 - v_e\,[1 - G_e(z)], \tag{27}$$

where $F_e(Q)$ — the probability of additional heat release; v_e — share of fire hazard failures (short circuit, break); $G_e(Z)$ — conditional distribution function (in the event of failure of the fire element) of a random variable $Z = \lg Q$, where $Q = k{\cdot}U{\cdot}I{\cdot}t$ — Joule heat of the fire element failure.

In this case, during the transition of the destruction and pyrolysis processes into a self-accelerating phase according to the criteria of Semenov and Frank-Kamenetsky, the heat release of a fire-hazardous failure leads to heating and self-ignition of the material of the failed RE. Another scenario is also possible. The heat release of a fire-hazardous failure "ignites" the neighboring RE according to the criterion of Zeldovich and Lyubchenko — Marchenko. This happens if the heat flux density is critical for the "neighbor" and its surface temperature reaches the ignition temperature.

RE failure rates must be determined by the modified Arrhenius — Eyring equation [72, 73]:

$$\lambda = A(P,V,N,F)\frac{\mathrm{k}T\,\cdot}{h}\cdot\exp\cdot\left(-\frac{E_a}{\mathrm{k}T}\right)\cdot\exp\cdot\left[f(H)\right], \tag{28}$$

where λ — current RE failure rate; $A = k_i{\cdot}\lambda_n$ — product of factors that are dependent on pressure, humidity, vibration, etc., as well as the nominal failure rate RE (λ_n); k — the Boltzmann constant; T — RE temperature; h — the Planck's constant; E_a — the effective activation energy of the RE failure; $f(H)$ — function non-thermal (energy) RE load.

The Arrhenius — Eyring equation (28) should be solved for each RE in the product by thermosounding the internal volume of the product $[T(t)]$ and the ambient air $[T_A(t)]$ while simultaneously measuring the energy consumed by the product $[E(t)]$ by solving the Navier-Stokes heat balance equations (direct and inverse problems of thermal location). As a result, the temperatures (T) and the current values of the energy load functions of each RE $[f_i(H)]$, are determined, and the values of the activation energy functions of each RE are selected on the "smooth surfaces" of the functions $[E_a(H,T)]$, obtained by solving equation (28) from three reference values of failure rates — storage, nominal and maximum permissible[74].

In this case, it is possible to determine the intensity of RE fire-hazardous failures ($\lambda_{fh} = \lambda_{H,T}{\cdot}v_e$) and the intensity of their ignition ($\lambda_{ign} = \lambda_{fh}{\cdot}F_e$), since the critical thermal parameters for each RE are known. Further, by integrating, it is possible to calculate the probability of RE ignition (F_{ign}), which will eliminate the methodological and logical incompleteness of the fire hazard assessment of any product or object. After that, by adding the heat capacity of the combustion of the ignited RE to the critical thermal parameters of the RE surrounding it, it is possible to calculate the spread of fire according to the same critical parameters, which will allow determining the probability of a fire in the product. [75].

Similarly, using expressions for entropy and energy (18), (19), the Arrhenius-Eyring equation can be used in entropic form:

$$\lambda = A(P,V,N,F)\frac{\mathrm{k}T\,\cdot}{h}\cdot\exp\cdot\left(-\frac{S_O}{\mathrm{k}}\right)\cdot\exp\cdot\left[f(H)\right], \tag{29}$$

where S_O — the entropy of the failure of the electric radio element. For the rest of the notation (28).

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[72] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
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Conclusions. The analysis of the main "fire" standards and norms revealed their inconsistency with the current state of science and technology. It is noted that fundamental science pays insufficient attention to "fire problems", which are applied problems of the theory of combustion and explosion, physical chemistry, thermophysics and thermodynamics.

The paper presents the results of the system synthesis of the main approaches in the theory of combustion (ignition) and methods and means of thermal and acoustic emission analysis. Thus, a probabilistic-physical method for determining the flammability and fire hazard of substances, materials, electrical appliances and household items is implemented. This will ensure the required level of protection of the population and objects of the technosphere from fires.

The entropy approach to diagnostics of safety and reliability of technogenic and natural systems where there are people is offered. In this case, the minimum acceptable security level is 0.999999.

The results of the revision of shortcomings and errors in fire safety standards and norms that arose due to the "industry" approach to their development and should be corrected are presented.

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Monitoring of the ecological state of the city lake of Chita

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Introduction. The paper presents the results of the studies on assessing the quality of the aquatic ecosystem of a lake located within the city. The European perch (Perca fluviatilis L.) and the Gibel carp (Carassius gibelio) were used as an indicator for determining the quality of the aquatic ecosystem by the method of fluctuating asymmetry.

Problem Statement. The aim of the work was to conduct monitoring with the subsequent assessment of the quality of the ecosystem of the city lake using the method of fluctuating asymmetry (hereinafter FA).

Theoretical and Practical Part. The quality of the urban lake aquatic ecosystem was assessed using the FA method (indicators: the European perch (Perca fluviatilis L.), 1758 and the Gibel carp (Carassius auratus Bloch), 1783). To identify the reasons for the high PFA values, a chemical analysis (in an accredited laboratory) of the gills of the Gibel carp for heavy metals was performed.

Conclusions. As a result of the research, the FA indicators values for these indicators were obtained. According to the results of a laboratory study of the content of heavy metals in the gill arches of the Gibel carp, an excess of the maximum permissible concentration of 8 out of 10 analyzed elements was revealed. It has been established that the ecosystem of the city lake Kenon is experiencing a significant anthropogenic load (5 points — the critical quality of the aquatic environment) and it continues to increase towards the deterioration of the habitat.

***Keywords*:** aquatic ecosystem, heavy metals, ecological state, environmental quality, fluctuating asymmetry (FA).

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Introduction. In the modern world, the problem of environmental pollution is becoming more and more urgent, since technological progress does not stand still. Both of these processes are inextricably linked with each other. With the growth of industry, the need for energy and raw materials is also growing, which are the main factors of negative impact on the environment. In this regard, the accumulation of heavy metals in soil, water bodies and living organisms is becoming more intense and dangerous. There are seven large thermal power stations located directly on the Trans-Baikal Territory, which are serious sources of pollution, including heavy metals. The largest producer of electricity and heat on the Trans-Baikal Territory is Chita TPS-1, located on the shore of Lake Kenon. It is also the only thermal power station that has been using a natural lake as a heat sink for 55 years. In addition, it is planned to complete the construction of the next stage of the TPS, which will undoubtedly worsen the ecological condition of Kenon Lake.

Problem Statement. The purpose of this work was to conduct monitoring with subsequent assessment of the quality of the ecosystem of the urban lake by the method of fluctuating asymmetry. The object of research is the natural lake Kenon, located within the city of Chita (Fig. 1).

Theoretical and Practical Parts. The object of research and over 50% of its catchment area are located within the boundaries of the urban area (western outskirts). The lake is located in the central part of the Chita-Ingoda intermountain forest-steppe basin. From the west, the Kadalinka River flows into Kenon Lake (27 km) with a catchment area of 94.2 km^2, from the north — the Zastepinsky stream, which originates from the Yablonovy Mountains [1].

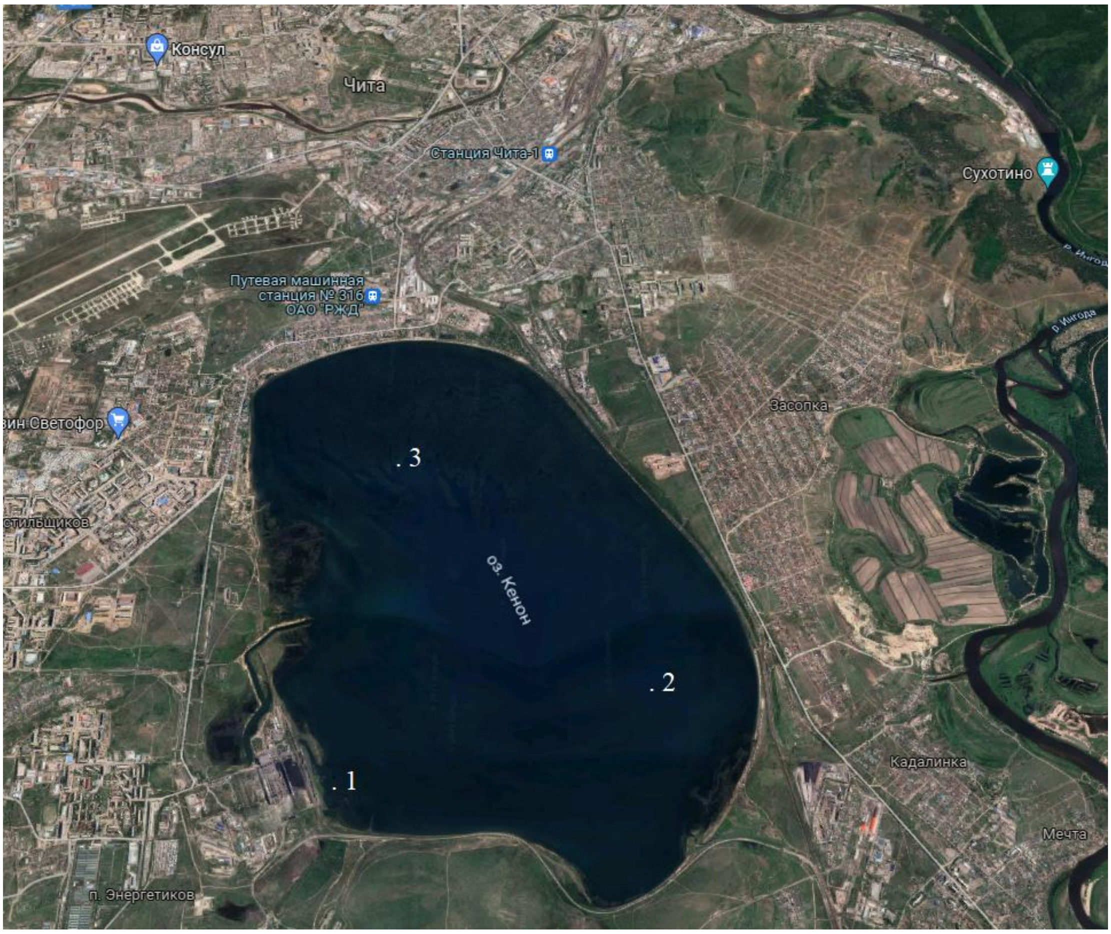

Fig. 1. Location of Kenon Lake

Kenon Lake is a heat sink for the thermal power station TPS-1, and is also used by the population as a place of rest mainly in the summer. The lake is unique, it is a natural water body located within the city and has a water surface area of about 16,200 m^2. It is the only lake in Siberia and the Far East located within the administrative center. In previous periods, the lake's water area was actively used for fishing purposes, since it was rich in large fish (pike, white amur, Siberian Roach, Amur catfish, carp, bighead, crucian carp, perch) [2]. Later, some fish species disappeared.

In 2010, a city beach was equipped on the eastern shore of the lake, which is currently functioning, which attracts more tourists and tourists here.

The hydrological features of the lake's water regime include the fact that it is fed mainly by groundwater, precipitation and small streams, in addition, water is periodically pumped from the outside through a pipeline laid from the Ingoda River in order to maintain the absolute level of 653 m to ensure the efficiency of the TPS.

The freezing period on the lake ranges from 180 to 215 days only in the southeastern part, since part of the water area located near the discharge of warm waters in the northwestern part does not freeze. This leads to intensive evaporation of water, as well as to a decrease in the ice cover in this part of the lake. As the lake is heat sink, the thermal balance of the water masses of the reservoir is disturbed, which certainly affects the state of aquatic organisms and aquatic vegetation.

A white amur and a Bighead carp were introduced into the city lake; the water level was raised in it by almost a meter [2, 3]. Because of this, the settlement areas were rapidly reduced, and in the central part of the lake, the Potamogeton crispus population disappeared [4].

Since some species of fish, including the Bighead carp and the white amur, have disappeared, there is currently a tendency for active development of aquatic vegetation, especially in places where warm waters are discharged, since the development conditions in them are most favorable.

The peculiarity of the bottom sediments of Kenon Lake is that it is covered with a small layer of dark gray and sometimes black mud. Its capacity in the western part of the research object is up to 0.3 m, and in the eastern part — up to one meter. Pollution of bottom sediments is modern and cannot be relict. The uneven distribution of bottom sediments was to some extent facilitated by the extraction of sandy soil from the bottom of the lake with the help of a dredger in the north-western part when the base was washed under the site of TPS-1 in the early sixties of the last century. According to the results of research in 2013, the excess of MPC for several chemical elements in various places of the water area was revealed [5]. The excess was recorded for the following elements: lead (Pb), arsenic (As), zinc (Zn), selenium (Se). In addition, an excess of the standards for benzapyrene was detected directly near the TPS and from the village of Kadala, as well as a tendency to its accumulation from the eastern part of the water area [5, 6].

The authors have assessed the quality of the aquatic ecosystem of the urban lake using the following methods:

— according to the FA method of European perch (Perca fluviatilis L.), 1758 and Gibel carp (Carassius auratus Bloch), 1783;

— optical method (atomic absorption spectrometry) was used to determine the quantitative index of heavy metals in fish tissues and organs (Gibel carp).

The low-cost method of fluctuating asymmetry (recommended by the Ministry of Natural Resources of the Russian Federation) makes it possible to determine the quality of terrestrial and aquatic environments [7]. The essence of this method is the determination of morphological features (symmetry) of plants and living organisms to assess the state of the environment. Except for the European perch the Gibel carp was additionally selected as a bioindicator for this method, which, according to the results of research in 2016, was recommended by the authors for bioindication purposes [3].

The researches using the above methods were carried out in the period from 2019 to 2020. Each sample of material (point) for the aquatic environment was 20 individuals of fish. The material was selected at three points (Fig. 1). Point No. 1 is located directly near the TPS-1. The material for the study was selected in the channel of warm technical waters discharge. Point No. 2 is located on the side of the southern shore of the lake, near the place of water supply from the Ingoda River. Point No. 3 is located in the northeastern part of the lake, near the recreational area.

After completing the measurements using the FA method of the Gibel carp caught in the winter-spring period of 2020, all the gill arches in each fish were removed and dried, after which an analysis was performed in the laboratory using one of the optical methods for the content of heavy metals in them. Using the MGA-915 atomic absorption spectrometer, the following heavy metals were determined in the gills of the Gibel carp: arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn).

The comparative analysis and data processing were carried out on a computer using the Microsoft Office Excel program.

Results and Discussion. The results of studies using the FA method of the European perch and the Gibel carp, shown in Table 1, confirm that the ecosystem of the urban Kenon Lake is experiencing significant anthropogenic stress (refers to the fifth point).

Table 1

Assessment of the aquatic environment quality (the level of deviation from the norm)

Year	PFA of perch (Perca fluviatilis L.)	Score	Environment quality	PFA of carp (Carassius auratus Bloch)	Score	Environment quality
2019	**0.61±0.001**	5	Critical	-	-	-
2020	**0.6±0.001**	5	Critical	**0.47±0.001**	5	Critical

In addition, the FA index of perch (Perca fluviatilis L.) has significantly increased compared to the data of the study conducted in 2009-2012 (0.46±0.001), which indicates a deterioration of the habitat [8, 9].

To identify the causes of high PFA, a chemical analysis was performed (in an accredited laboratory) of the gills of the Gibel carp for the content of heavy metals, as organs that are most susceptible to their accumulation. According to the results of this laboratory study, an excess of MPC was detected in 8 out of 10 analyzed elements (Table 2). Table 2 reflects the content of heavy metals in the gill arches of the Gibel carp in absolute (mg/kg) values. MPC of heavy metals in fish are established in accordance with the current document [10].

Table 2

The content of heavy metals in the gill arches of the Gibel carp

No.	Name of the element	Content, mg/kg	MPC, mg/kg
1	Cadmium	0.69	0.2
2	Nickel	3.7	0.5
3	Chrome	2.4	0.3
4	Zinc	544.9	40
5	Manganese	22.2	10
6	Copper	8.8	10
7	Iron	214.9	30
8	Lead	2.1	1.0
9	Arsenic	0.3	1.0
10	Cobalt	0.7	0.5

The content of cadmium was 3.45 MPC, nickel — 7.4 MPC, chromium — 8 MPC, zinc — 13.62 MPC, manganese — 2.22 MPC, iron — 7.16 MPC, lead — 2.1 MPC and cobalt — 1.4 MPC, the content of copper and arsenic in the gill arches of the Gibel carp does not exceed MPC. The results obtained indicate that the level of heavy metal pollution of fish in Kenon Lake is very high. First of all, this may be due to water leaks from the hydraulic ash dump, with the discharge of recycled water from the TPS-1, as well as with the watercourse formed as a result of leaks and discharges from the second lift pumping station [5].

According to the results obtained, it is clear that Kenon Lake is experiencing a strong anthropogenic load due to the complex impact of adverse factors. The entry of heavy metals into the reservoir is undoubtedly connected with the production process of the Chita TPS-1, since a large amount of solid fuel is burned during the operation of the thermal power station.

Kenon Lake needs systematic environmental monitoring, restoration of the ecosystem by reducing the anthropogenic load. Only strict quality control of discharged industrial waters, emissions of burned solid fuel, as well as a well-equipped hydraulic ash dump will reduce the negative impact on the reservoir.

As an object for comparing the values obtained by the FA method, the lakes Arachley and Shakshinskoye, located on the territory of the natural park, were selected. In the summer of 2019, the authors conducted a sample of the European perch in these lakes in order to assess the quality of the environment by the FA method. Table 3 shows the obtained results.

Table 3

The quality of the aquatic ecosystem of some lakes according to the FA indicator

Name of the lake	PFA of perch (Perca fluviatilis L.)	Score	Environmental quality (level of deviation from the norm)
The Arachley	**0.32 ±0.001**	**2**	Initial deviations
The Shakshinskoye	**0.25 ±0.001**	1	Conditionally normal

When comparing the results obtained, it can be seen that the environmental quality of Kenon Lake is significantly lower than that of the lakes of the natural park. Although both of these lakes experience a significant recreational load, they are located far enough from the city and industrial enterprises, so the level of anthropogenic load on their ecosystem is small [11].

Conclusions. The studies using the FA method revealed that the Kenon Lake water area has a high score of deviations assessment in the state of the organism from the conditional norm in terms of the PFA of developmental stability for fish. For the first time in the conditions of Eastern Trans-Baikal, the Gibel carp (Carassius auratus Bloch) was used as an indicator of the quality of the aquatic environment by the FA method, which showed good bioindicative properties.

In a comparative analysis of the results obtained during the research in the summer of 2019 and in the winter-spring period of 2020, it was found that the tendency to reach a critical level of the ecosystem of the reservoir has persisted. A comparative analysis of the environmental quality of Lake Kenon and Lakes Arakhlei and Shakshinskoye of the Ivano-Arakhleisk Nature Park revealed that the Arakhlei and the Shakshinskoye have a much better PFA. The results of the analysis of the content of heavy metals in the gill arches of the the Gibel carp showed an excess of the MPC for 8 out of 10 determined metals.

Thus, monitoring of the ecological state of urban Kenon Lake in the city of Chita showed that the quality of its ecosystem, determined by the method of fluctuating asymmetry, is assessed as critical. This is confirmed by a very high level of heavy metal contamination of fish (according to the results of a laboratory study of the gill arches of the Gibel carp). It is necessary to carry out regular comprehensive monitoring of this facility and work to improve the ecology of Kenon Lake.

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Contribution of the authors

V. V. Zvyagintsev — formulation of the main concept, goals and objectives of the study, conducting research, preparation of the text, formulation of the conclusions; O. Y. Zvyagintsev — analysis of the research results, revision of the text, correction of the conclusions; V. K. Chernyshov — collection of ichthyological material, conducting research, analysis.

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Comparative analysis of the impact of objects of traditional and alternative energy on the environment

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Introduction. Active withdrawal of energy raw materials from the subsoil, as well as technogenic impact from energy sources based on traditional fuel, lead to irreversible environmental consequences. To minimize this impact, it is necessary to start from two main conditions: the search for alternative energy sources and the improvement of the existing ones.

Problem Statement. The objective of this study is a comparative analysis of energy facilities in order to identify the plant that has the greatest negative impact on the environment.

Theoretical part. The comparative analysis of various energy production systems reflects the ecological and economic components of each. For example, a thermal power plant (TPP), a nuclear power plant (NPP) and a wind power plant (WPP) are considered. The negative impact on the environment is mainly exerted on the atmospheric air, in connection with which the data on the amount of pollutants are considered. Also, a modified Leopold matrix was constructed for an expert assessment of the mentioned stations.

Conclusions. The results of the analysis show that among the considered power plants, the wind power plant is the most environmentally friendly and favorable for the health of the population.

Keywords: wind energy, environment, air pollution, alternative energy source, traditional energy, comparison of energy systems, green energy.

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Introduction. Energy plays an important role in the development of the country's economy. This is due to the fact that no production process can be realized without the use of energy. Currently, there are two main problems in the energy sector: resource depletion and man-made impact on the environment. The exhaustion or non-renewability of natural resources is complicated by the unevenness of their location on the planet. Resource consumption leads to enormous changes in the biosphere. The removal of natural resources from the earth's crust disrupts the circulation of substances in nature. This entails a number of consequences, such as landscape changes, groundwater distribution, soil degradation, removal of areas of natural ecosystems both in the process of extraction and in the process of energy realization [1]. The problem of depletion of natural resources can be solved in two ways: the use of other (alternative) energy sources and energy conservation, i.e. improving the energy efficiency of the existing power plants and their rational use. The problem associated with the impact of energy enterprises on the environment increases with the growth of energy production rates. So, to date, man-made emissions into the atmosphere in the form of greenhouse gases from the energy industry account for more than 50%.

Most of the world's generated energy comes from thermal power plants. When fuel is burned at a thermal power plant, pollutants are released into the atmospheric air. Getting into the environment, they cause irreversible harm to human health. Penetrating in large quantities into the human body, they can cause acute poisoning, have an irritating effect on the mucous membranes of the respiratory and visual organs. Aluminum and silicon oxides can destroy lung tissue, leading to a disease such as silicatosis. In the places, where thermal power plants are located, the amount of oxygen in the atmosphere decreases, this is due to the fact that a significant proportion of it is spent on fuel combustion.

R. B. Goldman, A. S. Noskov, A. A. Peregonenko, D. A. Krylov and many others were engaged in research in the field of the influence of thermal power plants on the environment. D. A. Krylov presented specific indicators of the content of toxic elements in fly ash at Russian thermal power plants, these data allowed to assert that thermal power plants are sources of environmental pollution [2]. The research of the Institute of Fundamental Problems of Biology of the Russian Academy of Sciences assessed the pollution of Chelyabinsk and its environs with heavy metals (Cu, Co, Ni, Zn, Pb, Cd, Cr, Mo, Hg), the source of which are emissions from thermal power plants and boilers burning coal [3]. V. V. Yadutov, T. I. Petrov, Yu. N. Zatsarinnaya classified the forms of TPP influence on the environment:

— physical, related to acoustic, electromagnetic, radiation, thermal effects;

— direct, related to the introduction or removal of various components from the natural environment;

— indirect, including gravitational deposition of aerosols and solid particles [4].

Yu. A. Gradoboeva, I. V. Kondratieva, A. O. Margarint, A. S. Puzankov, M. R. Gafarov assessed the impact of nuclear power plants on the environment in their works. In 1988, the International Atomic Energy Agency developed a seven-level scale of nuclear events for the uniformity of the assessment of emergencies associated with accidental radiation emissions into the environment at nuclear power plants. According to it, the accident at the Three Mile Island nuclear power plant in the USA and the accident at Windscale (Great Britain) were assigned to the fifth level, and the accident at the Chernobyl nuclear power plant — to the seventh level of danger (global). When comparing the operating indicators of thermal power plants and nuclear power plants of the same capacity, it is obvious that the degree of negative impact of thermal power plants on the environment is much higher.

A. I. Zaporozhets, E. I. Sosnina, B. V. Ermolenko, M. A. Ryzhenkov, V. E. Vavilov, E. V. Andreeva, G. V. Pachurin, V. N. Beznosov considered the impact of wind power plants on the environment during their construction and operation. According to the research of Yu. A. Rolil, the direct physical impact of wind turbines is mainly associated with the laying of foundations, access roads and cables [5]. A.V. Gornostay and A.V. Bulekov estimated that during the life cycle of a wind power plant consisting of 12 installations, 2079 GW of electricity will be produced, which will reduce the emission of 2,491,200 tons of CO_2 into the atmosphere [6].

As the analysis shows, none of the presented works contains a comparative analysis of the environmental impact of all three power systems (thermal power plants, nuclear power plants and wind power plants).

Problem Statement. A significant reduction in the negative impact on the atmosphere can be achieved by switching to alternative energy. The prospects for the development of a complex of renewable energy sources are gaining momentum, in particular, this concerns wind power, which is a relatively young industry in our country. The relevance of the WPP lies in the fact that the raw material for generating electricity is wind, an inexhaustible source, which enormously reduces the consumption of the planet's resources [7]. The purpose of this study is a comparative analysis of energy sources with the choice of the object that has the greatest negative impact on the environment.

Theoretical Part. To compare wind power plants with traditional energy sources (thermal power plants and nuclear power plants), an analysis was carried out and factors that negatively affect the environment were identified.

TPP: influence on atmospheric air. Emissions from thermal power plants generated during fuel combustion contain pollutants: dust particles, carbon dioxide, nitrogen oxide, sulfur oxide, fly ash, sulfuric and sulfurous anhydride, fluoride pollution, gaseous products of incomplete combustion. To reduce the concentration of pollutants in the surface layer of air, thermal power plant boilers are usually equipped with chimneys 100-200 m high. Due to this, the scattering area increases by tens, and in windy weather — by hundreds of kilometers [8, 9].

Influence of TPP on soil. During the combustion of coal, a large amount of ash and slag waste is formed, for the storage of which the territories are needed, as a result of which lands are alienated for these needs. In addition, there is a radiation background in ash and slag dumps.

Influence of TPP on water bodies. The operation of a thermal power plant involves the use of a large volume of water that comes from the nearest water body, goes through a cycle and returns. At the same time, water is a source of thermal pollution, leading to the death of aquatic flora and fauna, changes in hydrological indicators, evaporation, erosion, transformation of the microclimate.

NPP: influence on atmospheric air. The impact of nuclear power plants on the environment begins from the moment of construction and continues to exist even after its operation. Thus, aerosol and gas emissions enter the atmosphere from nuclear power plants. Radionuclides, as a rule, are long-living, and every year, accumulating in the biosphere, they increase the dosimetric cost. The most dangerous is the isotope of hydrogen, whose half-life is 12.3 years, it is formed by irradiation of water, partially passing into steam and entering the air. Radiation destroys the tissues of plants and animals, leads to mutations, infertility, and with high radiation exposure — to the death of humans and animals [10].

Influence of NPP on water bodies. Only 40 % of the used water is returned to the cycle, moreover with waste. Radioactive substances trapped in rivers, seas, oceans are absorbed by aquatic plants and animals, which return to the human body through the food chain.

Influence of NPP on soil. From the soil surface, radioactive substances enter the roots of plants, and then into the body of animals, including agricultural ones [11].

WPP: influence on atmospheric air. The nature and sources of atmospheric pollution during the construction of wind power plants are similar to standard capital construction projects. Vehicles and construction devices, welding and painting works, the use of bulk construction materials are the main sources of environmental pollution. At this stage, the following pollutants enter the environment: carbon monoxide, sulfur dioxide, nitrogen oxide and dioxide, iron and manganese oxides, gasoline, kerosene, soot, inorganic dust, fluoride compounds, etc. During the operation of the wind power plant, there is a significant reduction in heat losses. For example, one generator with a capacity of 1 MW leads to a reduction in CO_2 emissions by 1,800 tons per year, which is about 900 million tons per year on the scale of the existing wind power plants. Pollution at the operational stage is so small that it is customary not to take them into account. Pollutants are released only during the production of wind turbine components. These include carbon monoxide, nitrogen oxide and dioxide, sulfur dioxide, gasoline, kerosene, soot, inorganic dust, iron and manganese oxides, fluoride compounds and other substances [12, 13].

Influence of WWP on water bodies. There is practically no impact on the hydrosphere. The water consumed during construction is usually used irrevocably in cement mortars. Possible pollutants may be stormwater wastewater containing suspended solids and petroleum products.

Influence of WWP on soil. At the construction stage, waste is generated in the form of concrete in lump form, bitumen, construction rubble, asphalt, scrap of non-ferrous and ferrous metals, remnants of welding electrodes, cables, and wires. At the stage of operation, there is no negative impact; moreover, the territories occupied for the construction of the wind power plant make up 1% of the entire station, which allows the territory to be used for agricultural needs

Influence of noise. The noise from a wind power plant consisting of 10 wind turbines at a distance of 350 m is 35-45 dBA, which is an acceptable indicator. For comparison: a car moving at a speed of 65 km/h at a distance of 100 m creates a noise of 55 dBA, and background noise in a rural area at night varies in the range of 20-40 dBA. The influence is quite subjective and depends more on individual factors of sound perception.

Influence of vibration. Vibration during the operation is associated with the movement of the blades. According to the calculated data, a wind power plant (wind turbine) of modern design does not transmit vibration waves to surrounding objects if the mass of its moving part is 16 or more times the weight of its moving part [14].

In order to compare the quantitative characteristics of emissions into the atmosphere from energy facilities, Table 1 is compiled.

Table 1

Annual release of pollutants into the environment from energy facilities with a capacity of 1000 MW

Pollutatnt		TPP	NPP	WPP
NOx, t		20 900	74	-
CO, t		210	49	-
CO_2, t		6 mil	6700	-
Solid particles, t		4500	-	-
Fuel oil ash/soot , t		73 000	3	-
Radionuclides, TBq	IRG	-	375	-
	Iodine	-	0.018	-
	CO^{60}	-	0.074	-
	Cs^{134}	-	0.0009	-
	Cs^{137}	-	0.002	-

Based on the expert assessment method, the authors have constructed a modified Leopold matrix for energy facilities (Table 2). The impact of thermal power plants, nuclear power plants and wind power plants on the objects are evaluated on a three-point scale, where 0 points — no impact, 1 point — minimal negative impact, 2 points — average negative impact, 3 points — maximum negative impact.

Table 2

Modified Leopold matrix for energy facilities with a capacity of 1000 MW

impact Object of impact	TPP	NPP	WPP
Atmospheric air emissions (quality)	3	1	0
Climate change (micro)	2	0	1
Soil (pollution)	2	2	0
Wastewater discharges	3	3	0
Waste generation	1	3	1
Noise	1	1	2
Vibration	0	0	2
Thermal effects	3	2	0
Occupied area	1	1	3
Flora	1	2	1
Fauna	1	0	1
Aesthetic need (landscape)	1	2	1
Consequences of accidents	1	3	0
Public health	2	2	0
Workers' health	3	2	0
Public safety	1	3	0
Safety of workers	2	3	0
Total intensity of exposure	28	30	12

The significance of all impacts is determined by the formula

$$\gamma = \frac{100}{n}, \tag{1}$$

where n — the number of cells in which the intensity of the impact is not zero.

Total intensity of exposure:

$$I = \gamma \cdot \sum_{i-1}^{n} \omega_i. \quad (2)$$

The results of the calculation showed that the lowest total intensity of the environmental impact is exerted by the wind power plant.

Table 3 shows comparative indicators: advantages and disadvantages of thermal power plants, nuclear power plants and wind power plants. The main advantage of wind energy is environmental cleanliness, and the disadvantage is its inconstancy [15].

Table 3

Advantages and disadvantages of energy facilities

	TPP	NPP	WPP
Advantages	– cheap raw materials – small investments in construction – construction is possible in any region – occupy a small area	– high output power – operation is cheaper than that of thermal power plants – do not require constant and large fuel supplies – no greenhouse gas emissions	– an inexhaustible type of energy used – wind – emissions into the environment are significantly reduced – quick assembly of the structure – occupied territories can be used for agricultural needs
Disadvantages	– non-renewable energy resources are used – a number of pollutants are released into the atmosphere – violation of the thermal balance of water bodies – consume atmospheric oxygen	– large capital investments – radioactive waste – the probability of an accident leading to irreversible consequences – a long period of dismantling work	– occupy significant territories – are located only in certain places – noise pollution – an obstacle to the spread of radioactive vibrations – threat of the death of wildlife – specific quality of metal per structure, which is charactezized by contamination in the production of parts

Conclusion. It is obvious that any anthropogenic activity has a negative effect on the environment, and it is impossible to achieve an absolutely environmentally friendly way of obtaining and selling energy, therefore it is necessary to constantly be in search of solutions to minimize this impact.

Based on all the facts and arguments presented in the article, it can be concluded that with a detailed analysis, taking into account and minimizing possible factors of negative impact on the environment, in particular humans, the wind power plant is the safest power generation station. Atmospheric pollution during the operation of the wind power plant is insignificant, compared with traditional energy. Even taking into account the CO_2 emissions during the production of materials and equipment for wind power plants, their safety is many times greater than thermal power plants. Reducing emissions into the atmosphere from the operation of wind power plants improves the quality of life of the population. And speaking on a global scale, such energy saves the resources of our planet

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Contribution of the authors:

Y. S. Borisova — construction of research goals and objectives, search for literary sources, analysis, text preparation, conclusions; N. S. Samarskaya —formulation of the concept of the article, the choice of topics, scientific supervision, analysis of the results, revision of the text.